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Julkaisun nimike
Strukturointi postponement-strategioiden toimitusketjun analyyttisella mallintamisella

Tiivistelmä
Tässä väitöskirjassa tutkitaan neljää erilaista massaräätälöinnin tyyppiä ja mahdollisuuksia integraation rakentamiseen toimittajien, valmistajien ja asiakkaiden välille kilpailuedun saavuttamiseksi. Menetelmänä käytetään positivistista paradigmaa kehittämällä postponement strategioita massaräätälöinnin ja integraation taloudellisten hyötyjen saavuttamiseksi.

Menetelmän avulla vastataan kahteen tutkimuskysymykseen, jotka ovat:

1. Kuinka postponement strategioita sovelletaan massaräätälöinnin toteuttamisessa?
2. Kuinka integroitumista hyödynnetään, kun tavoitteena on massaräätälöinti ja tehokkuuden maksimoiminen?

Tutkimuskysymyksiin vastataan kuuden artikkelin avulla. Kaksi ensimmäistä artikkelia koskevat ensimmäistä tutkimuskysymystä ja seuraavat neljä artikkelia vastaavat toiseen tutkimuskysymykseen.

Tutkimuksen tulokset korostavat postponement strategioiden soveltamista silloin, kun massaräätälöinnin strategioiden dynamiikka muuttuu suhteessa tuotteisiin ja prosessien muutoksiin. Tutkimuksen tulokset tukevat valmistettavan tuotteen prosessien, suunnittelun, toimituksien, valmistuksen ja markkinoinnin integroimisen tärkeyttä.

Tutkimus rajoittuu analyyttiseen mallinnukseen. Tulevaisuudessa on myös mahdollista kehittää empiirisiä simulaatiomalleja huomioimalla muuttujat ja ongelman kattavuus.Tutkimustulokset esitetään komponenttien yleisyysindeksin avulla, jotka yhdistetään tuotteen valmistukseen, tuotekehitykseen ja markkinointiin.

Asiasanat
Kumppanuus, markkinointi, massaräätälöinti, tuotekehitys, hankinta, tuotantoketjut.

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Abstract

The purpose of this thesis is to study four types of mass customization and find possibilities for building economies of integration among suppliers, manufacturers and customers in order to achieve competitive advantage

The methodology applies a positivist paradigm for developing postponement strategies and economies of integration to enable mass customization.
The methodology will answer two research questions, as follows

1. How do postponement strategies approach mass customization?
2. How do postponement strategies approach economies of integration to satisfy lead times and delivery reliability?

This dissertation proposes six papers to answer these two research questions. Two of them for the first research question and the other four for the second research question.

The results highlight postponement strategies as mass customization strategies for meeting product and process change dynamics. Furthermore, they support the importance of integrating product and process design to optimize supply, manufacturing and marketing decisions.

This research is limited to analytical modeling. However, it is also possible to develop empirical and simulation models in the future by considering the variables and coverage of the problem.

A metric for measuring component commonality and integrating manufacturing, product development and marketing shows the originality of these results.

Keywords

Collaboration, Marketing, Mass Customization, Product Development, Procurement, Supply Chains

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Abbreviations

APS	Advanced Planning and Scheduling
ASDN	Agile Supply Demand Networks
ATP	Available to Promise
MC	Mass Customization
R&D	Research and Development
RQ	Research Question
VMI	Vendor Managed Inventory

ARTICLES

1 INTRODUCTION, RECENT DEVELOPMENT AND STRUCTURE OF THE STUDY

For many years, it was common policy for manufacturers to produce in large batches to keep productionand ordering costs low. Unfortunately, the current trend in consumer requirements does not support this idea any longer. Consumers wish to be served according to their own “special needs” and the variety of products is increasing. Obviously, this makes production lines busier with frequent setup and down time due to the higher product variety. Inline with this idea, a manufacturer needs to develop a closer relationship with suppliers in order to maintain their service level.

1.1 Introduction to mass customization

The term “mass customization” (MC) was coined by Stanley M. Davis (1987) in his book “Future Perfect”, and it was further developed by Pine (1993), who defined it as “processes for low-cost, volume production of great variety, and even for individually customized goods and services” (page 7). Furthermore, the author mentioned that achieving MC could be optimized by producing a standard platform which allows the production of a myriad variety of final products. This concept has been re-discussed by making a clear differentiation between variety and customization. Variety means anticipating customer demands by putting product choices in outlets and hoping some customers will choose the products, while customization means giving customers exactly what they want (Pine, 1993).

Related to the MC objective, Pine (1993) proposed four types of value chain reengineering based on differentiation of the customization stages. In general, product and service customization represent the differentiation. The higher customization degree in the value chain processes requires quick response manufacturing. Originating from this idea, in application Hart (1995) proposed the four pillars of MC in pursuing an explicit MC strategy, namely customer sensitivity, process amenability, competitive environment, and organizational readiness.

In considering the four pillars of MC in terms of manufacturing and service operations, process amenability requires manufacturing process customization and customer sensitivity requires service customization. Manufacturing process customization and service customization support a competitive strategy in sustaining a competitive environment by exploring the capabilities to measure organizational readiness. Thus, it is essential to study MC from a competitive strategy point of view in pursuing competitiveness (Hart, 1995).

1.1.1 Definition of mass customization

Even if MC has been previously defined (Pine,, 1993; Davis, 1987; Kotha, 1995). it is still not a simple concept to comprehend. This research proposes two concepts of MC according to a management vision and production management paradigm in order to explore the future needs for MC.

1.1.1.1 MC as a management vision

As a management vision, MC is the ability to make profits in providing customers with anything they want, any time they want it, anywhere they want it, and any way they want it (Davis, 1987; Pine, 1993; Hart, 1995). In other words, the vision of MC is to offer competition based on strategic flexibility (Hayes and Pisano, 1994) in order to sustain competitive advantage (Kotha, 1995). Thus, MC as a vision necessitates a manufacturing role that should also provide the required flexibility (Hayes and Pisano, 1994).

MC as a management vision seeks the competitive advantage of the firm by creating knowledge throughout the entire organization. Knowledge creation extends organization knowledge by gathering information from employees and end users in order to apply MC as strategy for knowledge creation and organization learning (Kotha, 1996), together with competitive advantage, as competitors cannot obtain this information.

Based upon the literature review, MC as a management vision has the following characteristics:
1. MC is a strategy for achieving competitive advantage by creating knowledge in the entire organization.
2. MC is a customer focus strategy in providing customers with anything they want profitably, any time they want it, anywhere they want it, and any way they want it.

1.1.1.2 MC as a new paradigm in production management

In addition to MC studies on competitive strategy (e.g. Boynton et al, 1993; Lampel and Mintzberg, 1996), MC has also been studied in terms of manufacturing strategy (e.g.Westbrook and Williamson, 1993; Kotha 1996) to represent MC as a new paradigm in production management (Davis, 1989) by controlling its focus on responsiveness and flexibility (Pine, 1993). The flexibility discussed here is focused on mix and volume flexibility (Alderson, 1950; Bucklin, 1965; Zinn and Bowerzox, 1988; Zhang et al, 2003; Su et al, 2005) by achieving machine, labor, material handling, and routing flexibility as manufacturing competencies to achieve manufacturing capability. Indeed, Zipkin (2001) added elicitation (a mechanism for interacting with the customer and obtaining specific information) as a third MC focus. Thus, the focus of this new paradigm is on production process in terms of manufacturing strategy.

In enabling mix and volume flexibility, the development of a commonality metric (Martin and Ishii, 1996; Jiao et al, 2000; Blecker and Abdelkafi, 2007) and component modularity degree (Mikkola, 2007) supports product development strategy. Furthermore, Sharifi (2006) proposed design for the supply chain to meet manufacturing process and product development coordination. Thus, manufacturing agility is the goal of MC in terms of manufacturing strategy.

Based upon the literature review, MC as a new paradigm in manufacturing strategy has the following characteristics:

1. Flexible manufacturing processes to offer individually tailored products or services on a large scale by developing manufacturing capabilities to produce customer satisfaction (Zhang, 2003)
2. MC enables agile manufacturing by coordinating manufacturing process and product development process design (Sharifi et al, 2006).

1.2 Mass customization in the literature

It is important to investigate different perspectives on MC to finding discrepancy and congruency. This analysis paves the way to develop future MC application models to support business practices. This section is composed of three subsections. Section 1.2.1 discusses MC as a competitive strategy. Section 1.2.2 discusses MC in the context of manufacturing. Finally, section 1.2.3 discusses MC in the context of marketing and procurement. These three sections view MC from the backend of the value chain (procurement) to the front end (marketing).

1.2.1 MC as a competitive strategy

MC as a source of competitive advantage has shifted the paradigm in competitive strategy by changing from price oriented mass marketing to segmented marketing strategy (Kotler, 1989) and at the same also shifted the production strategy from mass production to MC (Kotha, 1996). On the other hand, MC is also constrained by high production technology, elaborate systems for meeting customer wants, strong logistics systems, and personalization (Zipkin, 2001). Personalization requires the firm to be different not only in manufacturing but also in marketing by satisfying the cumulative requirements of price, quality, flexibility and agility by applying information and operational technologies (Kumar, 2008). Finally, faster knowledge exploitation through innovation over competitors is the key to achieving competitive advantage (Cooke, 2008).

Knowledge exploitation in MC contributes to the manufacturing capability in terms of flexibility (Narashiman and Das, 1999) by producing a significant source of differentiation, a unique signature to the organization and future advantage consideration (Prahalad, 1993), brand identification, specialization, push-pull strategy, channel selection, product quality, vertical integration, cost leadership, price policy, service, and relationship with the parent company (Porter, 1980). Exploiting knowledge is important in terms of value creation by generating strategic flexibility (Kotha, 1995). One example of knowledge exploitation is the case of the National Bicycle Industrial Company (NBIC), where knowledge sharing between mass customized and mass production plant generates direct communication from the end customer to the production floor (Kotha, 1995). A second example is a study of the Honda experience, which gives us an insight into putting emphasis on flexibility and efficiency as two sources of its success in the "New economy." Honda headquarters in Japan provides the core technologies from which its subsidiaries provide process flexibility (Sonoda, 2002). This example signifies that customization level determines the level of flexibility and time to market (Kotha, 1995).

Flexibility in terms of mix and volume flexibility (Zhang, 2003) enable a firm to offer tailored products or services on a large scale (Zipkin, 2001) that require collective action of technology, governance process and collective learning (Prahalad, 1993). On the other hand, Pine (1993) insists on generating these flexibilities by injecting long-term investment in capital, human and technological, in the new competition to increase variety and customization. This is the paradigm of MC (Pine, 1993).

In conclusion, MC as a competitive strategy must consider process change and product change (Boynton et al, 1993) in terms of product variety and process efficiency at minimum cost. Furthermore, stable product and process change can be obtained by analyzing component commonality and modularity (Jiao and Tseng, 2000 Mikkola, 2007; Blecker and Abdelkafi, 2007), where cost minimization can be achieved by assigning strategic inventory (Graves and Willems, 2000; 2008). While operations capability such as product platform modularity and postponement are the keys of operations capability, they will not be achieved without considering competitive strategy when pursuing MC (Safizadeh et al, 1996; Brown and Bessant, 2003).

1.2.2 MC in the context of manufacturing

When considering MC as a new form of competitive strategy, then global supply chains also force manufacturing strategy to be integrated into MC (Watts et al, 1995; Tseng and Du, 1998). The application of the manufacturing paradigm tree for mass customization (Tang et al, 2005) provides conflict resolution among the three order winners of customization, zero customer lead times and low cost. Decoupling the process capability in terms of product and process commonality to increase flexibility as a prerequisite of long-term stability (Tang et al, 2005) can synergize these three order winners. In supporting the paradigm, we synergize the order winners by reconfiguring the product options (Du, et al, 2003) and optimize the manufacturing strategy to satisfy customer wants such as price, flexibility and agility (Kumar, 2008). Furthermore, this research also supports the concept of agile manufacturing in term of e-commerce by reducing gap between manufacturing and marketing by identifying customer needs through concurrent engineering (Gunasekaran and Yusuf, 2002). Thus, concurrent engineering enables MC by aligning customer and supplier into product development (Shariffi et al, 2006).

In conclusion, the discussion on the MC in the context of manufacturing leads us to extend MC discussion from product oriented to customer-oriented strategy. This finally forces manufacturing manager reconsider about competition and rapid changes into manufacturing strategy.

1.2.3 MC in the context of marketing and procurement

Jiao and Tseng (2000) mentioned that the way to achieve MC is by letting customers compose their own design, illustrating the multi-dimensional decision making process of product architecture development (Tseng and Du, 1998). The descriptions of customers and requirements have to be defined in order to analyze the requirements for obtaining knowledge of functional structural and technical design of the product family structure (Agard and Kusiak, 2004). Thus, customizing production visibility to the customer via customerization represents MC in the context of marketing (Wind and Rangaswamy, 2001).

In addition to the customer-marketing interface, producing competitive advantage by extending the array of sourcing frameworks has replaced the current trend in strategic sourcing decision-making from cost reduction to the ability of core competence identification (Venkatesan, 1992; Sislian and Satir, 2000). If the manufacturer does not have the capability (resources and time) to invest in strategic activities, then strategic sourcing is the option. Thus, a strategic item or activity that has high impact on and risk for the buyer is appropriate for strategic sourcing (Kraljik, 1983).

Strategic sourcing triggers a strategic partnership with suppliers. Thus, for MC, a firm may outsource strategic but non-core competence activities by requiring that the suppliers achieve the best in their class in innovation while the main firm can focus on its core competence activities and concentrate its whole resources to achieve competitive advantage (Porter, 1980). Without arguing against the previous literature, the discussion of MC leads us to the agile approach (Brown and Bessant, 2003; Sharifi et al, 2006), which is not only discussed in terms of process, but also strategy, people and linkage to obtain an agile supply chain through-supply chain design. This finally forces the manufacturing manager to reconsider the issues of competition and rapid changes. While information sharing is a key to operations capability, it cannot be achieved without considering product development and supply chain integration when pursuing MC (Brown and Bessant, 2003; Sharifi et al, 2006).

To that end, marketing and purchasing strategy support MC by aligning them to manufacturing strategy in order to create continuous improvement (Boynton et al, 1993). In addition, information technology architecture brings about modularity, flexibility, and reusability in designing systems to support integration and control. Thus, the development of information sharing and physical flow coordination is the key to supply chain business process management (Lambert and Cooper, 2000) in marketing and procurement.

1.3 MC in business practice

More companies are applying a mass customization effort to improve their competitiveness, for instance the business practices in Dell computers (Lee, 2004), Hewlett Packard desk jet printers (Feitzinger and Lee et al, 1997), Amazon (Kassmann and Allgor, 2006), and Phillips Personal Garment Care (Sanchez, 2002). One of them, Hewlett Packard (HP), established the Strategic Planning and Modeling (SPaM) group to apply more radical approaches, namely the realignment of manufacturing and distribution strategies, improvement in forecasting techniques and methods and product and process redesign for supply chain management.

HP strategy has further investigated the application of logistics and manufacturing postponement strategy (Lee, 1996). Furthermore, Feitzinger and Lee (1997) reinvestigated this strategy by modularizing the power supply and postponing the assembly of the product. The other example of the paper is how to redesign the production process to postpone the customizing process just after the order comes. The important outcome of the research is how to optimize supply chain performance by building coordination among marketing, research and development (R&D), manufacturing and distribution and finance activities.

The second example is taken from Phillips Personal Garment Care (Sanchez, 2002), which creates a platform strategy for strategic flexibility. The platform strategy separates components into common and varied parts, in which the common parts are grouped into modules, according to their functionality. An example of this application is the powered toothbrush using different styles and features not directly related to basic brush-tip design, and motion also became an important basis for product differentiation by the late 1990s.

The third example is Dell Computers' virtual integration that insists on the manufacturers specializing and stitching together the business with partners. One important piece of information from this example is that mass customization also opens the possibility for outsourcing strategy. This outsourcing definition, however, is different to the traditional thinking of outsourcing where the buyer also outsources his or her problems. Indeed, risk sharing emerges as a form of supply chain collaboration. In this case, Dell Computers is not just cost effective and fast, but also agile, adaptable and aligned (Lee, 2004).

From the three above examples, mass customization best practices can be categorized into three properties, namely agility, adaptability and alignment, in order to achieve a quick response to highly varied demands (Lee, 2004). This conception is interesting since the three examples represent at least one of these: Dell Computers for alignment and agility, HP postponement strategy for agility and adaptability and Phillips Personal Garment Care for agility and adaptability. The questio now emerges in regarding to the "Triple A" Supply Chains (Lee, 2004) of "how to assess the most suitable "A" strategy to our organization?" This question is important since it going to streamline the manufacturing strategy as well as supply chain and marketing strategy to achieve competitive advantage in the market.

Product differentiation strategy, overall cost leadership and focusing on a particular buyer group can achieve competitive advantage (Porter, 1980). Focus strategy is the important one since it combines overall cost leadership and product differentiation. This implies that MC should be focused on a certain market target by maximizing customer expectation on product quality through product differentiation and winning competition against broader focused competitors through overall cost leadership. Thus, investigation of the development of MC methods is important in order to find out the state of current research and the future needs of MC.

1.4 Research problem

This research categorises the problem of MC systems using previous literature as follows (Fisher and Foreit, 2002).
A potential research situation arises when three conditions exist:
1. A perceived discrepancy exists between what is and what should be.
2. A question exists about why there is a discrepancy.
3. At least two possible and plausible answers exist to the question.

We will use these three situations to locate theresearch problem. Section 1.3.1 finds out the discrepancy between current MC and the need for future MC. Section 1.3.2 finds out all possible causes of the discrepancy. This dissertation uses the causes to analyse the required postponement strategies for meeting the requirements of future MC.

1.4.1 Perceived discrepancy between "current mass customization" and "the needs for future mass customization"

Silveira et al (2001) identified six success factors for MC systems: these are market condition appropriateness, the existence of a demand for variety, readiness of the value chain, availability of technology, customizable products, and knowledge sharing. Knowledge sharing enables highly intensive communication between MC and mass production (Kotha, 1995), where it implicitly highlights the importance of value chain reengineering to enable this communication. Thus, supply chain integration and coordination is essential for MC by optimizing information flows (Staedtler, 2005).

Furthermore, Fogliato et al (2003) support supply chain integration and coordination by developing a system-wide MC by integrating product development and manufacturing strategy (Tseng and Du, 1998). The development refers to all product development, production, and supply chain costs that would be incurred in developing and realizing new product variations over the lifetime of the platform to consider design for the supply chain (Sharifi et al, 2006).

In a strategic level discussion of MC, however, this integration and coordination issue was rarely discussed in the light of the new concept of postponement strategies (Van Hoek, 2001). There is a growing stream of publications on postponement in various disciplines (see, for example, Feitzinger and Lee, 1997 on strategy; Garg and Tang, 1997 on operations research; Van Hoek et al, 1998 on logistics). However, Van Hoek (2001) mentioned that the increased production of knowledge on postponement mean that, after 30 years of incubation, the principle has not been integrated in managerial practice and academic research. Postponement strategies have been acceptable in application (Bowersox et al, 1995). Morehouse and Bowersox (1995) predict that it will increase in application, to the extent that by the year 2010 half of all inventory throughout the food and other supply chains will be retained in a semi-finished state waiting for finalization, based upon customer orders. There are well-known case studies of companies that have grown (Dell: see Magretta, 1998) and flourished (HP: see Feitzinger and Lee, 1997) through postponement. These studies suggest that in terms of managerial practice, postponement is not new, either in conceptualization or in application, to innovative companies. Perhaps we should interpret the growing interest in, and application of, postponement as a rediscovery of the concept. In that case, we want to find out what is new and what has changed.

In conclusion, postponement application to enable MC needs a global supply chain perspective. The previous research struggles on an academic perspective, thus the discussions have been only partial. For instance, some of the literature concentrates on component commonality studies (Collier, 1981; Martin and Ishii, 1996) to enable postponement strategies.However, some of the required supply chain strategies are ignored. For instance minimizing total inventory costs at widely dispersed networks ((Lee and Billington, 1994; Su et al, 2005) to support strategic flexibility and agility for developing competitive manufacturing strategy (Hayes and Pisano, 1996; Shariffi et al, 2006).

1.4.2 Why is there a discrepancy between "current mass customization" and "the needs for future mass customization"?

The absence of a supply chain perspective for postponement design might be the answer to the question. The problem is that the academic literature has tried to maximize the benefits of postponement strategies by designing product family to maximize product reusability.This effort will minimize product life cycle and development time (Jiao et al, 2004). As a result, product based decision making is pursued to minimize mass confusion, and as a result customers often do not have sufficient knowledge of the product specification which corresponds to their needs (Piller, 2004). Correspondingly, Vesanen (2008) and Kumar (2007, 2007b) proposed mass personalization for pursuing design collaboration between customer and producer. It seems that previously research tried to develop customer based MC but ignored lead times and delivery reliability as two parameters of customer satisfaction.

However, developing customer-based MC should go beyond the lead times and delivery reliability previously used (Lee et al., 1993; Zinn and Bowersox, 1988). Any customer will want fast and reliable order fulfillment. Customization, however, might pertain to functionalities, product specifications, and the degree of customer-defined component selection (Van Hoek, 2001). Since a company needs to pursue fast and reliable order fulfillment, then the study of MC needs to be extended to study the implementation of selected supply chain structures, where it is possible to make change management through agile supply demand networks (Helo et al, 2006). Given the comprehensiveness of these elements and the potentially supply chain coordination and integration, an agility concept might be advisable here.Generalizations on points and degree of application along the supply chain can be developed in relation to market operating circumstances and contingencies. In order to close the loop, these findings can be used as input to new postponement and supply chain initiatives.

In conclusion, discrepancy between current research and the future needs of customer-based MC can be eliminated by developing MC in global supply chain perspective.Thus, supply chain coordination and integration should be pursued where it promotes economies of integration.

1.5 Research objective and research questions

Although the reviewed literature is helpful in drawing attention to postponement as an enabler for MC, it fails to address many important details. First, it suggests that performance improvements result from competitive strategy initiatives manifested in their implementation via value co-creation (Piller, 2004). a value chain model can analyze value creation by assigning costs to value adding activities and deciding on a make or buy analysis to perform a firm strategy in postponement better than the competitors. Thus, efficient information flows perform value creation.

Recent investigations on postponement insist on technology and management methods for providing the required flexibility and responsiveness by optimizing product design and configuration (Collier, 1981; Jiao and Tseng, 2000; Piller, 2002; Salvador et al, 2002; Mikkola and Larsen, 2004; 2007; Huang, 2007). Moreover, Kumar (2007; 2007b), and Vesanen (2008) extends the discussion into Information Technology (IT) by pursuing mass personalization in the area of marketing. However, this discussion is limited to the downstream of supply chains and final customer communication. How to apply this IT to the overall supply chain is still emphasized in ERP as an everyday operation tool. There still a lack of IT design that can manage postponement as an enabler for supply chain design and reconfiguration.

Furthermore, in considering global competition, postponement strategy needs to investigate the possibility of supporting supplier relationship and managing the supply chain and product development simultaneously (Shariffi et al, 2006). Motivated by this deficiency, this research revisits the ideas of Zhang et al (2003) on using postponement strategies as the main instrument in enabling MC in the context of global supply chains. Thus, this research formulates two research questions, as follows:

Research question (RQ) 1

The goal of MC is to undertake the low cost production of individually customized products and services (Pine, 1993). Thus, this research revisits postponement strategies as an enabler of MC, and supports it with component commonality strategy. Moving from this idea, it is important to revisit the basic business idea of becoming competitive (Porter, 1980) by generating strategic flexibility (Kotha, 1995) to exploit the firm's capability for customers (Zhang, 2003). Pine (1993) proposed four aspects of MC to enable strategic flexibility. Strategic flexibility requires overall competitive positioning in the market by identifying capabilities as sources of competitive advantage and does not attempt to guide short term choices between conflicting priorities (Hayes and Pisano, 1994).

Alderson (1950) and Bucklin (1965) proposed postponement as a marketing capability for reducing lead times as well as inventory costs. Postponement strategies can provide the required flexibility by giving lower process change in times of turbulent demand change. Appropriate distribution of postponement strategies into four types of MC will enhance a firm´s competitive positioning in the market by giving the required manufacturing capabilities. Thus, this dissertation proposes the first research question as *"How do postponement strategies approach mass customization?"*

Research question (RQ) 2

Attention to the firm's capabilities in terms of flexible manufacturing strategy delivers what are called mix and volume flexibility for enhancing competitive position (Zhang et al, 2003). However, Wall Mart has proved that procurement, logistics, and marketing capabilities are also needs to be considered in order to win the competition (Stalk et al, 1992). Wall Mart also showed that building efficient information flows is the prerequisite of a supplier's integration. The integration of suppliers, manufacturers, and customers must be included in creating values in terms of price, quality, flexibility, and agility (Fine and Freund, 1990; Vesanen, 2007; Kumar, 2007b). Moving manufacturing efficiency beyond the historical level and ensuring maximal efficiency and operational fit with operational objectives in terms of price, quality, flexibility, and agility (Hopp, 2003) needs the integration of suppliers, manufacturers, and customers. Moving from this requirement, this research therefore formulates the second research question, as follows:

How do postponement strategies approach economies of integration for satisfying lead times and delivery reliability?

Solving these two research questions through analogical theories will explain relationships within supply chains (suppliers, manufacturers and customers) in borrowing from well-understood models and by suggesting that the explained system behaves in a similar fashion to that described by the well-understood models. Thus,the results are predicted from application of the rules of of the original theory. In following the research questions, this section focuses on locating the research objective, as follows.

1.6 Research objective

The two research questions present the future research directions in MC in general and postponement strategies in particular. They cover three elements, namely competitive advantage, customizable product and process, and technology support (Silveira et al, 2001). Furthermore, the level of customization, considering customer penetration point, service customization, information technology involvement and quality related issues (quality control and product reliability) exploits the viability of manufacturing capability. From the above considerations, this dissertation objective is:

<u>To extend postponement strategies from the supply chain perspective to achieve economies of integration.</u>

In considering the above objective, this research finally chooses a definition of extended postponement strategies, as follows:

<u>"The use of economies of integration to achieve competitive advantage by producing varied and often individually customized products and/or services</u>

<u>at the low cost of a standardized, mass production system (Pine, 1993) through the support component commonality".</u>

To support the definition, this research investigates information and physical flow application in mass customization by incorporating logistics, product design, and marketing strategy

1.7 Structure of the study

This work consist of five sections, Section 2 will carry out a further literature review from previous similar research. The literature review investigates the current state of development in postponement strategies and future directions of the strategies.

Section 3 details the research methodology based on research paradigms and the problems of developing an appropriate model for the research objectives of this research. This section will explore the essence of each proposed paper for answering the research questions.

Section 4 explores the author´s contribution by presenting the findings of the included papers. This section also builds a further framework for the research by presenting a comprehensive conclusion developed from research questions 1 and 2. The contribution of the author also extends the current state of MC strategies.

Section 5 explores the issue of research validation by giving some examples from the literature. This study does not intend to use the developed analytical models for specific industrial application. Instead, they will convince and guide readers and researchers in MC about the future research direction based on several case examples.

Sections 6 and 7 outlines the research conclusions and discuss the benefits of the proposed papers for managers.

2 LITERATURE REVIEW

The term postponement strategy was coined by Alderson (1950) and Bucklin (1965), who launched this idea as a marketing strategy. Since then, other concepts have also been introduced to enable the application of postponement, for instance modularity, introduced by Starr in 1965 (Ernst and Kamrad, 2000), and followed by introducing Moscato's commonality metric in 1976 (Blecker et al, 2007). Thus, the combination of postponement and commonality/modularity is an effort to integrate economies of scale and scope (Pine, 1993).

The combination of postponement and commonality/modularity brings in marketing capability in terms of price, quality, flexibility, and agility (Kumar, 2007; 2007b). Furthermore, other benefits of marketing capability support customer-based MC by merging the personalization concept (Vesanen, 2007; Kumar, 2008). More support for combining postponement and commonality/modularity comes from Kotha (1995), who proposes postponement as an operational flexibility to support strategic flexibility by considering learning and development (Adler, 1988).

There are three major aspects of choice in terms of flexibility type and measures to be used in practice. They are: (1) the competitive strategy of the firm, (2) the different types of variety and uncertainty that may exist in the external and internal environments, and (3) the manufacturing process configuration that may provide different types of flexibility (Gupta and Goyal, 1989; Ramaresh and Jayakumar, 1991; Fogliato, 2003). A global view of postponement supports these aspects by delivering marketing capability in terms of price, quality, flexibility and agility.

In supporting competitive strategy as an aspect of choice of flexibility types, Watts et al (1995) furthermore propose purchasing, manufacturing, and distribution strategy as three functional strategies to support competitive strategy. Furthermore, consistency in terms of cost, technology quality, delivery dependability and flexibility must be derived from corporate competitive strategy. Creating a partnership-like relationship with the supplier helps both buyers and suppliers in improving capabilities that impacts on cost, quality, delivery, and flexibility performance, so that recognizing and incorporating this new supplier relationship is critical (Watts et al, 1995). Postponement strategies are useful to create partnership-like relationships with supplier component commonality. This component commonality enables postponement application by putting some inventories in component form, and at the same time creating rapid product customization (Zhang et al, 2003).

Besides operational and supply flexibility benefits, postponement creates marketing flexibility by extending the previous concept into price postponement. This concept brings price as a competitive weapon instead of process flexibility (Wind and Rangaswamy, 2001) by customizing the selling price relative to the degree of customization and tailoring it to a specific user. Thus, price postponement is appropriate for satisfying customers by allowing them to compose their own "special needs."

Dudey (1992) introduces price postponement as dynamic edgeworth-bertrand competition in order to solve dynamic competition under capacity constraint. The Dudey model assumes that customers come to the market at different times and the firm's price can be reset at any time with an opportunity that at least one of the duopolists can sell all the units it is able to produce. Similar to the approaches of Dudey (1992) on price, Singh and Vives (1984) focus their analysis on flexible capacity/price appropriateness to hedge against predetermined price/quantity contracts. Their analysis adapts to a new demand or price after making a price or delivery quantity contract formerly under the absence or presence of product variety. The research, however, shows that even price can be postponed in order to hedge against demand variety.

In extending recent postponement applications, it is essential to consider the importance of managing the information flows between partners in supply chains as a form of supply chain integration and coordination. The emergence of network economy forces firms to comprehend and maximize the impact of these new information flows. Postponement should consider three dimensions of supply chains: these are monetary flow, goods flow and information flow. This situation triggers firms to utilize efficient communication between themselves and these new suppliers and distributors (Van Hoek, 2001).

The need for information flows develops supply chains in coordinating activities "across the supply chain to create value for customers, while increasing the profitability of every link in the chain." (Anderson, et al., 1997) This coordination aspect brings in the important, but largely ignored, role of *information flows* that complement the *physical flows* in the analysis of the supply chain.

In conclusion, the study of postponement comprises physical flows and information flows within supply, production, product development, and marketing strategies. There is a need to increase the discussion on information flows by considering supply chain alignment to hedge against market pressure on customization. Thus, economies of integration as the new concept of postponement need collaboration among procurement, manufacturing, and marketing functions within organizations and suppliers and end customers to create competitiveness.

This section reviews some literature on postponement strategies. In addition, modularity and component commonality literature is also surveyed to find directions for this research on meeting the needs for MC.

Table 1. Some literature on postponement.

Authors	Focus area	Idea
Alderson (1950).	Marketing channel.	Postponement is used to reduce various marketing costs because of the product itself and/or the geographical dispersion of inventories.
Bucklin (1965).	Logistics channel.	A combination principle between postponement and speculation, putting a speculative inventory at each point in a distribution channel whenever its costs are less than the net savings of postponement to both buyer and seller.
Zinn and Bowerzox (1988).	Logistic channel.	Postponement is used for increasing manufacturing flexibility by using labeling, packaging, assembly and final manufacturing at the final stage of production. Furthermore, postponement is also used for reducing lead times and product availability by putting the final product at the closest selling point.
Lee H.L (1996).	Manufacturing channel.	Postponement is used to enable product proliferation by controlling inventory level and lead times.
Feitzinger and Lee (1997).	Distribution channel.	Modular product supports postponement by developing agile supply networks.
Garg and Tang (1997).	Manufacturing channel.	Push and pull strategies are used to define postponement strategies in different manufacturing channels.
Birge (1998).	Manufacturing channel.	Price and capacity postponement is used to optimize the profit of substitutable products.
Pag and Cooper (1998).	Logistics channel.	Postponement strategies are divided into manufacturing and logistics postponement in order to divide between speculative and postponement strategies.
Van Hoek et al (1998).	Logistics systems.	Postponement strategies effect the formation of network organization.

(Table 1 Postponement literatures continued)

Author(s)	Focus area	Idea
Miegham and Dada (1999).	Manufacturing and marketing channel.	Postponement in terms of price and production is used to reduce investment and inventory uncertainty by reducing timely demand information.
Ernst and Kamrad (2000)	Logistics channel.	Postponement is appropriate to decentralized supply chains where suppliers and buyers have their own decision authority.
Johnson M.E and Anderson E (2000)	Manufacturing channel	Form postponement is used to design common product platform as an intermediate product before the customization stage
Van Hoek (2001)	Supply chain view.	The need for extending postponement strategies into the supply chain perspective.
Yang and Burns (2003).	Distribution channel.	Postponement is used to allocate inventory whether in part form (manufacturing postponement) or in final form (logistics postponement).
Swaminathan and Lee (2003).	Manufacturing channel.	Product and process reengineering are used to enable postponement by increasing their commonality or modularity.
Biller et al (2006).	Demand uncertainty mitigation.	Price postponement is used to adjust profit according to different demand levels.

On the other hand, some of the literature in MC emphasizes product family analysis for maximizing product platform reusability and reducing total costs through its alignment with process platform design (see Table 2). Table 2 shows the importance of component commonality and product modularity in supporting postponement strategies by providing the required operational flexibility.

Table 2. Some literature on component commonality and product modularity.

Authors	Focus area	Idea
Evans (1963; 1970)	Optimization of product modularity	To match between component and module for minimizing supply and production costs.
Rutenberg (1971)	Component commonality.	To minimize aggregate safety stocks level by developing component commonality index.

(Table 2 Product family analysis continued)

Authors	Focus area	Idea
Collier D, A (1981)	Component commonality.	To minimize aggregate safety stocks level by developing component commonality index.
Thomas (1991)	Commonality analysis	Cluster strategy for reducing the variety of water tank specifications.
Jiao and Tseng (2000)	Commonality indices development to understand product family	Component commonality and process commonality is developed to conduct feasibility study of product family
Martin and Ishii (1996)	Developing concept of design for variety.	Building component commonality, differentiation point, and set-up cost to allow the decision makers to estimate some of the generally unmeasurable costs of providing variety.
Thonemann and Brandeau (2000)	Optimal commonality in component design	To optimize component commonality to reduce number of components variants.
Simpson et al (2001)	Concurrent engineering is used to meet standardization and differentiation strategies.	Product variety tradeoff evaluation method for assessing product platforms alternatives to optimize individual product performance
Mikkola and Gassman (2003)	Developing modularity function	Develop modularization function based on the number of components and the degree of coupling between them.
Mikkola and Larsen (2004)	Supply chain integration implication to MC strategies.	Component commonality is useful to support modularity strategy to enable supply chain integration.
Blecker and Abdelkafi (2007)	Developing commonality metric for MC.	Customer preference is included in the metric development
Mikkola (2007)	Product modularity for MC.	Understanding product modularity and its effect to customization degree
Jiao et al (2007)	Design for MC by composing process platform planning.	Coordination from design to production through general product and process platform
Fixson (2007)	Review on modularity and component commonality researches.	Studies on commonality is less emphasized than modularity and the effect of those researches to quality, time and variety is less than that of costs effect.

From Table 1 and 2, we can see that postponement, component commonality and modularity are complementary. Modularity, as laid out in Evans' work on modular design (Evans, 1963; 1970), was described as the problem in which to determine the best configuration of small multi-use parts (in Evans' case, kits of screws) to satisfy a variety of demands. Commonality, in contrast, was the idea of using identical components in a one-per-product setting, but in different products.Downward compatibility (Rutenburg, 1971) allowed the use of one type of component in multiple products.Twenty years later, Thomas (1991) viewed commonality as a partitioning problem and suggested clustering techniques for its solution. More recently, the commonality optimization approach suggested by Thonemann and Brandeau (2000) uses a logic that strives for common parts to be identical, often also implying downward compatibility.

Table 3. Some literature on product platform effect on supply chains.

Authors	Focus area	Idea
Salfizadeh (1996)	Product and process matrix	Postponement and modularity/component commonality planning must be linked
Novak and Eppinger (2001)	Make or buy decision	To assess make or buy decision by considering product complexity
Durray (2000; 2004)	Modularity as an enabler for MC	Combination between modularity and customer order decoupling point significantly affect MC configurations.
Fixson (2005)	Design for SC for coordinating product development and supply chain	To link among product, process and supply chain decision by product-process strategy combination
Hofer and Halmann (2004;2005)	Component and layout commonality	Extension of product plaform usability from product family to product portfolio. This extension enables process commonality for different market share
Dong and Chen (2005)	Component commonality effects to supply chain performance	Component commonality can greatly reduce the inventory of a supply chain and improve its performance.

(Table 3: some literatures on MC effects to supply chain continued)

Shariffi et al (2006)	Design for SC for co-ordinating product development and supply chain	Providing guidance to product design at concurrent engineering application
Huang et al, (2007)	Product platform and supply chain configuration integration	Choosing on several possible modules of product platform by considering supplier capability
Ro et al, (2007)	Product modularity benefit to supply chain coordination	Modularity gives significant impact supply chain coordination, outsourcing and product development
Wilkner et al (2007)	System dynamic analysis for MC for representing supply chain coordination	Providing system dynamic analysis to cover demand agility at constrained capacity.
Fixson (2007)	Modularity and commonality research in terms of supply chain coordination	Studies that incorporate modularity and commonality multiple effects on various players along the supply chain, and that follow systems over time appear very promising.
Vesanen (2007)	Mass personalization as a form of marketer and customer collaboration	To collaborate marketer and service provider in terms of product or service, price, promotion and delivery.
Kumar (2007b)	Mass personalization as a form of marketer and customer collaboration	MC is lack of knowledge in terms of supply flexibility cost and required knowledge for customer co-creation
Brabazon and McCharty (2004)	Virtual built to order as MC order fulfillment process	To provide product reconfiguration capability by implementing postponement strategies at different decoupling point.

This research summarizes Tables 1 to 3 as follows:

1. Product and process design and supply chain coordination are the three areas of MC research
2. There is a trend in postponement strategies to incorporate the supply chain perspective into their application.

3. Supply chain perspective in a global view requires coordination and integration according to agility, adaptability, and alignment. Thus, supply flexibility, component commonality, and/or product platform modularity can be applied to various players along the supply chain if there are information flows from the supplier to customer and vice versa (Lee, 2004).
4. Postponement strategies need a commonality either in component or process, or even both, to achieve production line flexibility (Ma, 2002). In fact, production line flexibility influences price flexibility since most price changes can be accounted for by changes in direct costs for labor and materials (Yance, 1960), where it signifies the importance of component commonality to improve process flexibility.

2.1 Some insights from the literature

Besides time and form postponement, other forms of postponement strategies, namely price and production postponement, also influence the strategic investment decision of the firm and its value (Miegham and Dada, 1999). Price postponement is believed to be a reliable strategy to hedge against demand uncertainty, where it is good for investment and production decision in terms of production capacity and inventory level. However, the price and production postponement decision are not generally applicable to all business types. Some situations, for instance, need production postponement to reduce waste, or, in some situations, price postponement is more appropriate for high volume and high mix production.Furthermore, in relating to component commonality, there is the question of when and in what situation price and production postponement are appropriate with the absence or existence of product commonality.

In addition to previous literature, competitive postponement strategies are introduced in this dissertation.The reasons for applying competition into postponement decisions are twofold. First, the competition level influences the strategic investment decision (production capacity and inventory level) of the firm and its value,with the result that, secondly, the higher level of competition increases the value of the postponement decision (Miegham and Dada, 1999).Thus, a higher competitive level induces postponement strategies, which increase their value by carrying out customization in the final manufacturing stage in a shorter period: for instance, when a manufacturer introduces a new product. After investing in capacity, the firm announces either production quantity or price information. Then, in response to the revealed market demand, an appropriate production quantity or price is set. An example of this type is where most retailers have a commitment to order at a certain quantity from a manufacturer as a form of business contract, and most manufacturers announce price lists in advance in order to attract customers.

With regard to the insights, this dissertation developed a methodology that introduces the importance of competition in postponement strategies. The implication of this dissertation is that product managers, operations managers and logistics managers can broaden their view in a global and autonomous supply chain perspective. The difference with previous perspectives is that in global and autonomous networks a firm cannot act as a leader without considering other partners´ benefits. In conclusion, the development of competitive postponement strategies is essential to build a new concept in postponement strategies.

3 METHODOLOGY

This section starts with methodology as the focal point and only addresses the background for the readers in order to understand the motivation of this research, how and why the research methods and techniques were chosen in answering the research questions. Thus, this section presents a comprehensive framework within which this research operates.

First, a research paradigm describes the research assumptions of reality and knowledge.There are four alternatives research paradigms: positivist/postpositivist, interpretivist/constructivist, transformative and pragmatic (see Table 4).

Table 4. Research paradigms, methods and examples.

Paradigm	Methods (primarily)	Data collection tools (examples)
Positivist/ Postpositivist	Quantitative methods	The object of study is independent of the researchers; knowledge is discovered and verified through direct observations or measurements of phenomena; facts are established by taking apart a phenomenon to examine its component parts
Interpretivist/ Constructivist	Qualitative methods predominate, although utilization of quantitative methods may also possible.	Knowledge is established through the meanings attached to the phenomena studied; researchers interact with the subjects of study to obtain data; inquiry changes both researcher and subject; and knowledge is context and time dependent
Transformative	A mix of qualitative and quantitative methods. Contextual and historical factors described, especially as they relate to oppression	Diverse range of tools - a particular need to avoid discrimination, eg: sexism, racism, and homophobia.
Pragmatic	Possible use of qualitative and/or quantitative methods. .	May include tools from both positivist and interpretivist paradigms. E.g. Interviews, observations, testing and experiments.

(Adapted from: MacKenzie. N and S. Knipe, 2006)

3.1 Research ontology

Ontology involves the philosophy of reality, In considering the research ontology, naïve realism (Guba and Lincoln, 1994) was finally chosen. The reasons can be summarized as follows:

1. Quantitative research quantification is limited in nature, looking only at one small portion of a reality that cannot be split or unitized without losing the importance of the whole phenomenon. However, quantitative research is predominant in science and assumes that science quantitatively measures independent facts about a single apprehensible reality (Healy & Perry, 2000). In other words, the data and its analysis are value-free and the data do not change because of observation. That is, researchers view the world through a "one-way mirror" (Healy & Perry, 2000).
2. In terms of the ontology element, this research uses naïve realism because the reality that is considered in this thesis is real and apprehensible (Guba and Lincoln, 1994). Furthermore, this thesis investigates how to apply *postponement strategies* in *logistics, product design and marketing* work to support MC operations and this requires quantitative analysis. The findings must be true in terms of their application by giving evidence from measureable analytical modeling. This research does not want to use constructivism because the aim of this dissertation is not to transform the current postponement strategies by proposing a very new idea for current postponement strategies, but rather to understand the actions of decision makers rather than changing them or their approach to strategy formulation. Furthermore, nor does this research use a constructivist paradigm because it is not appropriate for business research requiring the kind of measurement required for our research questions. The purpose of this thesis is simply to stick to what we can observe and measure. In other words, we can conclude that our research area covers logistics, product design, and marketing decision optimization, where it is closer to theory testing research (Healy & Perry, 2000).

3.2 Research epistemology

Research epistemology addresses how we come to know that reality by identifying the particular practices used to attain knowledge of it. A dualist/objectivist approach was chosen (Guba and Lincoln, 1994). The reasons can be summarized as follows:

A dualist/objectivist approach guarantees the generality of the research outcomes because the analytical models are developed according to general rules in many industrial fields. Particular practices are identified, for instance how prices have changed according to demand changes, or vice versa (Singh and Vives,1984), and how higher component commonality affects product substituability (Lee, 1996). Thus, all analytical models follow common acceptable behavior in industrial practice, where the analytical models try to optimize the outcomes such that they are better than the previous research.

3.3 Research methodology

In considering the research methodology, experimental or manipulative approaches have been chosen. The reasons can be summarized as follows:

1. In optimizing logistics, product design and marketing strategy, we do not attempt to involve humans and their real life experiences. Indeed, I attempt to extend current applications, for instance the use of response analysis in built to order supply chain and manufacturing process and product design for designing the supply chain.
2. The focus of this research is on optimizing information flows in the area of logistics, product design, and marketing to support MC. Thus, the developed tools are largely mechanistic.
3. In terms of research epistemology, this research does not suppose that several operators of analytical models would give widely different outcomes. Indeed, the outcomes of this thesis are true findings that can be used in general. Further development of analytical models into computer software applications will give replicable answers by considering application areas.

3.4 Research Design

This section explores research design in terms of its operationalization (section 3.4.1) and details the methods to answer RQ 1 and RQ 2 (section 3.4.2 to section 3.4.7).

3.4.1 Operationalization of the Research

RQ 1 focuses on finding manufacturing capabilities through postponement strategies distribution across the four types of MC to generate competitive advantage. Thus, analytical models are developed and used as research methods by making analogy from previous well-established theories. This research uses postponement types to represent a firm's capability in MC. The reason is that postponement will minimize process change dynamics as well as maximize product change dynamics. Thus, the results of the research can develop guidance in deciding on MC systems optimization.

RQ 2 focuses on finding economies of integration by using postponement strategies to satisfy lead times and delivery reliability. Analytical models are developed and used as research methods also by making analogy from previous well-established theories. This dissertation uses five characteristics of a good theory, namely ability to account for data, explanatory relevance, testability, prediction of novel events and parsimony (Bordens and Abbots, 2002). Some problem examples from existing literature show the developed models´ testability and ability to account for the data. Each model tends to a specific situation, for instance buyer-supplier relationship, a firm and its competitor relationship, supplier competition, functions of relationships within a firm to represent the models' explanatory relevance. Furthermore, the novelty of each model gives a new insight into the previous literature and the comprehensiveness of the models shows the parsimony of the developed theory. For instance, the postponement strategy models combine the previous postponement strategy concepts that were separately discussed. Thus, the developed models build a thread among several postponement strategies, in this case price and production postponements and time and form postponement strategies.

In addtion to RQ2, value chain re-engineering gives benefit to economies of integration to optimize postponement strategies. Therefore, this research develops analytical models of Advanced Planning and Scheduling (APS) to represent suppliers, manufacturers, and customer integration. Simulated information and data signify that the models fit at any different data level. Empirical information regarding model parameters are not applied by considering that the previous literature has given enough information regarding the required main and important variables for model development For example, the price model of widely acceptable capacity and product substitutability independent variables. The costs model is composed based on widely used production, setup, holding, investment and order costs.

In conclusion, without ignoring other research methods, this research excludes the application of discrete event simulation because the area of the research is the strategic and tactical level. A second reason for this is that most previous research in MC used analytical models (Fixson, 2007), since analytical models are more appropriate for solving the efficiency and optimization problem. Other methods, for instance case study are more appropriate for theory building or finding new variables for maximizing the impact of postponement strategies on customer satisfaction. Discrete event simulation makes it possible to introduce a random number generator to represent operations performance and it can be used to optimize manufacturing competencies (machine, material handling, labor and routing flexibility) (Zhang et al, 2003). However, that is outside the scope of this dissertation.

3.4.2 Framework of research design

This research divides the discussion into five research papers that answer RQ 1 and RQ 2.Two papers were prepared to answer RQ 1 and one book chapter and three papers for RQ 2. The developed analytical models will answer both RQ 1 and RQ 2. This research excludes other methods such as discrete event simulation, empirical studies, case studies, reviews, and experimentation (Fixson, 2007) since mathematical models are more appropriate for solving efficiency and optimization problems. Other methods are more appropriate for theory building or finding new variables for maximizing MC impacts on customer satisfaction.

Applications of different analytical models are not mutually exclusive, so that a combination of several, and occasionally all of them together, provides drastic change and improvement throughout a firm's organization, including development and production (Pine, 1993). Thus, combining them gives benefit in supporting MC systems from different perspectives (Pine, 1993).This benefit goes to a firm that can maximize its manufacturing, marketing, and procurement capability in market turbulence demand and innovation by empowering the organization's resources.

Below is the framework of research design based on some publications

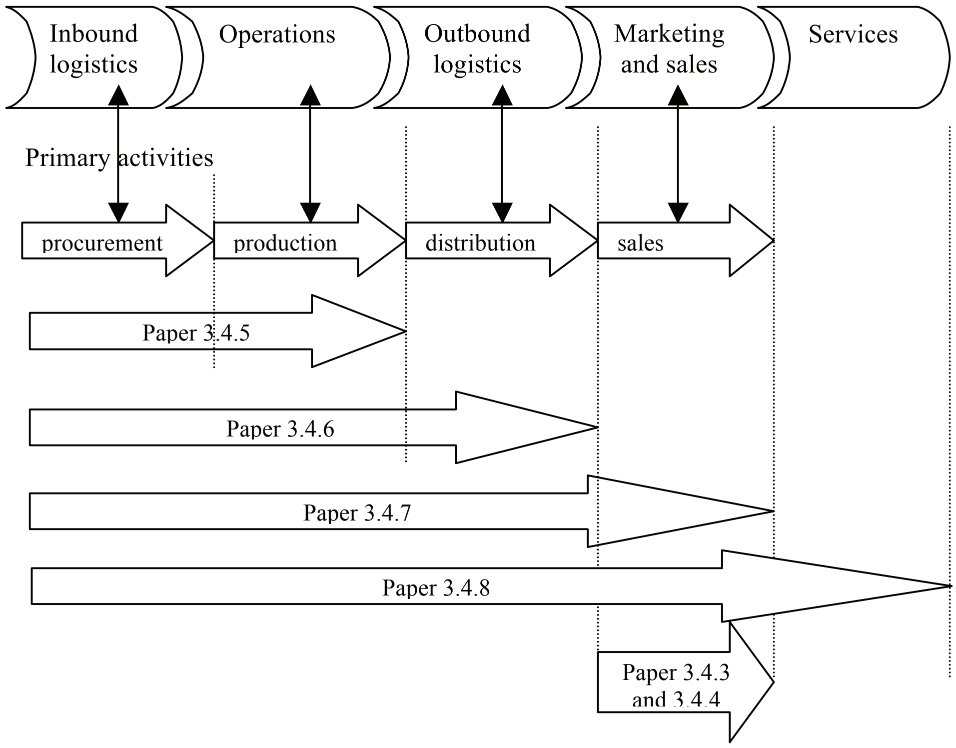

Figure 1. Composition of papers for value chain building.

Figure 1 shows that each paper covers a different area of the value chain. Papers 3.4.3 and 3.4.4 are intended to answer RQ1, papers 3.4.5 to 3.4.7 to answer RQ2. RQ1 is used by marketing to decide on what postponement strategy fits their needs. From the marketing decision, the operational decision (papers 3.4.5 to 3.4.7) is then elaborated through procurement, production, and distribution decisions. Finally, the supply chain decision monitors the outcomes of the marketing and operational decisions in terms of inventory value, lead times, and profitability by developing Agile Supply and Demand Networks (ASDN).We can see the relationship amongst the decisions in Figure 2.

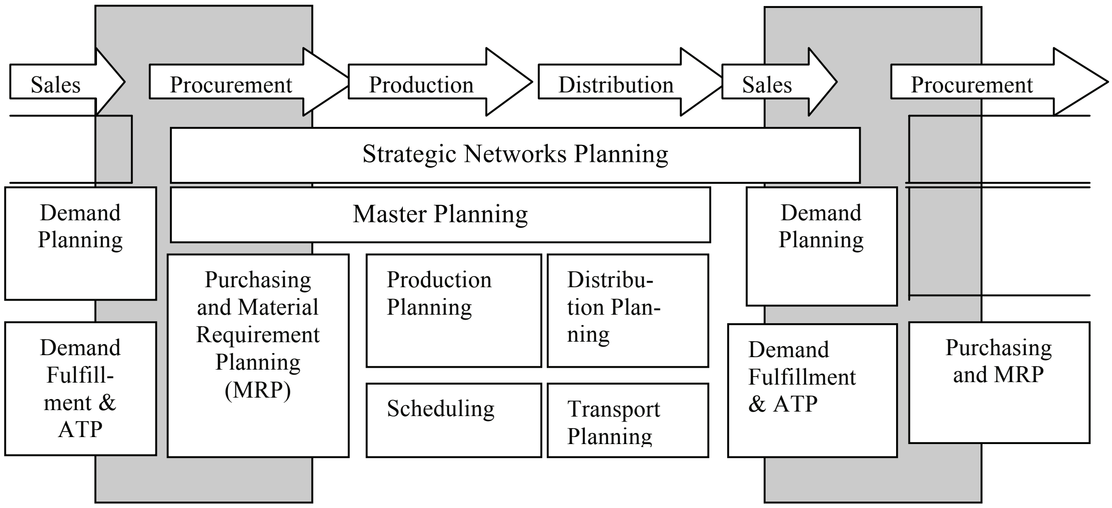

Figure 2. Interaction among several value chains by developing Advanced Planning and Scheduling (APS).

Figure 2 shows the interaction among value chains for optimizing supply chains as a whole in terms of Agile Supply Demand Networks (ASDN). Furthermore, one paper discusses this interaction in detail.One additional feature of this interaction is that the supply chain is able to decide on the sourcing decision, customer order decoupling point and availability to promise (ATP).

Thus, below is a summary of the essence of each paper for answering RQ1 and RQ2

1. Research Question 1: *How do postponement strategies approach mass customization*?

In answering Research Question 1, section 3.4.3 uses dynamic prices and quantity postponement strategies, and section 3.4.4 time and form postponement strategies to investigate their appropriateness in different conditions, for instance customer requirement specifications (high or low product substituability) and component prices from suppliers (component price at fixed prices or at discounted prices at different levels of order).

3.4.3 Dynamic Prices and Quantity Postponement Strategies (Kristianto. Y, 2010)

This paper addresses flexible price and production as marketing tools in customerizing customer orders. Flexible price (called price postponement) is intended for highly configurable product application, while flexible production (called production postponement) is focused on highly customized products that share limited components or modules with other products. The models are tested by using randomized demands and prices to investigate the profitability of price and production postponement.This paper uses product substitutability degree to represent the customization degree when compared with other products from competitors that have a similar function. It concludes that price postponement is appropriate for highly substitutable products and production postponement for highly differentiable products.

Clearly, this paper uses a combination of different postponement strategies to represent their appropriateness in different market conditions. This paper can be used to support marketing strategies in terms of volume flexibility (Zhang et al, 2003).Volume flexibility at lower product substitutability is achieved by applying production postponement and price postponement for higher product substitutability.

3.4.4 Time and Form Postponement Strategies under Dynamic Behavior of Demand (Kristianto. Y and Petri Helo, 2009a)

Time and form postponement addresses the location of the customization process and level of component standardization as marketing tools in the customization of customer orders (Lee, 1996). In brief, time postponement refers to delaying the various product differentiation steps (manufacturing, integration, customization, localization and packaging) as late as possible.Form postponement aims at standardizing the upstream stage as much as possible. Thus, time postponement refers to cosmetic customization, while form postponement to adaptive customization. The models are tested by using randomized demands and prices to investigate the profitability of the two types of postponement. It concludes that time postponement is appropriate for lowly substitutable products and form postponement for highly differentiatable products, at discounted prices at different order quantity.

This paper clearly uses a combination of different postponement strategies to represent their appropriateness in different supply conditions. This paper can be used to support procurement strategies in terms of volume flexibility (Zhang et al, 2003). Mix flexibility at lower product substitutability is achieved by applying form postponement and time postponement for higher product substitutability.

1. *Research Question 2: How do postponement strategies approach economies of integration for satisfying lead times and delivery reliability?*

In answering Research Question 2, section 3.4.5 uses dual sourcing strategy to minimize supply uncertainty. Section 3.4.6 uses response analysis to investigate the benefit of component commonality to postponement strategies. Section 3.4.7 uses strategic inventory allocation to give guarantees on lead times. Section 3.4.8 integrates the ideas of section 3.4.3 to section 3.4.7 into Agile Supply and Demand Networks (ASDN) to measure the benefit of postponement strategies.

3.4.5 Strategic Thinking in Supply and Innovation in Dual Sourcing Procurement (Kristianto. Y and Helo. P, 2009b)

This paper represents purchasing strategy by studying a buyer and two supplier's strategic moves in order to gain competitive advantage over suppliers, by considering the buyer and the suppliers' payoffs. Thus, selling price optimization for the buyer and suppliers, as well as the innovation level through product substitutability signifies strategic competitiveness.The results show that innovation in terms of developing component commonality supports postponement strategies by making available to promise to the customer and giving benefit to suppliers by increasing the component price at a higher level of component commonality.

With respect to managerial implication, the paper suggests that the buyer should encourage innovation by offering higher incentives to the suppliers, as well as imposing penalties for lack of promptness in supply.This research suggests that strategic thinking is appropriate for highly customized and innovative products. The novelty of the research is in the formulation of competitive strategy in dual sourcing where innovation is encouraged.

The paper proposes procurement strategy formulation to give strategic response to a rapidly changing competitive environment. The paper presents supply flexibility in terms of benefit and cost analysis by considering supplier and manufacturer integration. The paper is thus used to respond to the economies of integration by maximizing supply efficiency and creating value in terms of flexibility and quality. As a result, attempts to apply dual sourcing strategy are designed for achieving flexibility in the promised supply.

3.4.6 *Strategic Thinking in Supply and Innovation in Dual Sourcing Procurement (Kristianto. Y and Helo. P, 2009b)*

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With respect to managerial implication, the paper suggests that the buyer should encourage innovation by offering higher incentives to the suppliers, as well as imposing penalties for lack of promptness in supply. This research suggests that strategic thinking is appropriate for highly customized and innovative products. The novelty of the research is in the formulation of competitive strategy in dual sourcing where innovation is encouraged.

The paper proposes procurement strategy formulation to give strategic response to a rapidly changing competitive environment.The paper presents supply flexibility in terms of benefit and cost analysis by considering supplier and manufacturer integration. The paper is thus used to respond to the economies of integration by maximizing supply efficiency and creating value in terms of flexibility and quality. As a result, attempts to apply dual sourcing strategy are designed for achieving flexibility in the promised supply.

3.4.7 *Built to Order Supply Chains: Response Analysis with Control Model (Kristianto. Y and Helo. P, 2010b)*

This paper addressescontrol systems modeling in built–to-order manufacturers facing customized demand. The general purpose of the paper is to present a novel approach to managing collaboration, by considering information exchange between the manufacturer and the supplier. The methodology applies feedback control into postponement strategy of built-to-order (BTO) to analyze supplier-buyer collaboration (production capacity and promised lead times and supply flexibility). The application of tournament game ahead of control system application will minimize the effect of supply uncertainty, with the ultimate goal being profit maximization. In terms of the dynamic of MC in terms of component commonality effects on various players along the supply chain, this paper visualizes the effect of product design decision in reducing lead time variability and increasing production process change stability by keeping the level of product variety (Boynton et al, 1993; Pine, 1993). Furthermore, pursuing supply contract and promising supply delivery promptness reflect the improvement in the benefits of the supply chain.

The paper proposes a tool of innovative management to give strategic response to rapidly changing competitive environments. The paper thus proposes information technology application in product development and supply strategy to meet the new challenge of manag a firm´s responsiveness and responding to the dual competitive requirements of responsive delivery and production efficiency. Thus, this paper is used to respond to the economies of integration by maximizing supply efficiency and creating value in terms of flexibility, delivery, and quality.

3.4.8 Designing for Supply Chain by Coordinating Manufacturing Process and Product Development Process (Kristianto. Y and Helo. P, 2010c)

This paper focuses on decision-making related to the coordination between product development process and manufacturing process to represent marketing strategy and manufacturing strategy in terms of the product development process. This coordination is important in terms of agility requirement (Sharifi et al, 2006). Furthermore, in terms of MC as a competitive strategy, discussion on agility is important since it is a part of the core competencies in manufacturing by combining flexibility and leanness or cost consciousness (Takala, 2002). The paper supports postponement strategies by producing component commonality and investigates its effects on various players along the supply chain and supply flexibility.

A manifestation of manufacturing process development is through push pull manufacturing strategy, where it incorporates supplier and customer demand information to decide on the Customer Order Decoupling Point (CODP). CODP represents the degree of customer involvement in the manufacturing process. .

The benefits of postponement strategies through managing product variety are appears in component commonality analysis.The introduction of a new commonality measure represents a form of customer involvement in product development. Analysis of customer requirements by using Multi Criteria Decision Making (MCDM) signifies customer co-creation by giving product information and reconfiguration to the customer. Furthermore, the linking of this index to manufacturing strategy optimization guarantees that product varieties are handled appropriately by assigning their manufacturing process to the right decoupling point and customer service level.

Production capacity decision made by considering supply variance and production process variance reflects the cost of supply flexibility in terms of guaranteed lead-time. The new approach of strategic safety stock allocation minimizes the cost of flexible supply. Thus, the cost of flexible supply is linked directly to a firm's total costs in order to investigate its effect on the supply chain cost structure.

Clearly, designing for the supply chain supports economies of integration by aligning customers to the production and product development processes. This paper develops marketing capability in using mix and volume flexibility. Mix and volume flexibility enable a firm to apply price and production postponement to support marketing capability and flexibility (Zhang et al, 2003), thus, maximizing efficiency and fitting operational objectives in terms of price, flexibility, agility, and delivery.

3.4.9 Value Chain Re-engineering by the Application of Advanced Planning and Scheduling (Kristianto. Y, P. Helo and A. Mian, 2010d)

This paper details value chain re-engineering by utilizing the new concept of Advanced Planning and Scheduling (APS).The methodology applies collaboration among suppliers, buyers and customers to fulfill orders.The paper exploits the benefits of network economy in terms of promised lead-time, inventory allocation, and supply strategy and revenue maximization.

The models show that it is possible to re-engineer the value chain by incorporating the supply side (suppliers) and demand side (customers) within the new concept of APS. A problem example shows how to implement this concept by emphasizing important aspects of the supplier and customer relationship. This concept, however, does not take account the importance of service and customer interface and transport optimization; hence, the research excludes the effect of customer requirement.

The proposed APS, however, depends on the above mentioned postponement strategies. Furthermore, the integration of the proposed APS and Agile Supply Demand Network (ASDN) requires many extensions in terms of ASDN building. This innovation makes a contribution to ASDN as well as APS in viewing the value chain as a macro form by including the supply and demand sides.

3.5 Analysis

3.5.1 RQ 1: How do postponement strategies approach mass customization?

Papers 3.4.3 and 3.4.4 support RQ 1 by giving a new insight into managerial decisions on mass customization in a supply chain perspective. One notable result is that price and production postponements as well as time and form postponements have a strong relation to component commonality and product modularity in terms of MC. This relation is important since until today there has been no published paper wholly devoted to this area. As a result, postponement strategies are emphasized in the firm´s capability to delay product differentiation without considering supplier reaction.The effect of this discrepancy is significant since the supplier and buyer relationship motivates different types of postponement.

Figure 3 shows that adjustable component price and product substitutability degree (higher product substitutability signifies a lower level of component commonality or product modularity) motivate supply chains to apply form and/or time postponement. In defense of the results, it is often in practice so that the component price is different at different levels of order size to attract more buying quantity and to create economies of scale in terms of quantity discount. On the other hand, production and price postponement is very common in a business to-business transaction to minimize the total costs of satisfying demand by fixing the order quantity to the component supplier. Finally, we can summarize the results from paper 1 and 2 as in Figure 3 below

Table 5. Postponement types according to MC systems.

Economies of scale to exploit quantity discounts	Form postponement	Time postponement
Economies of scale to exploit fixed costs	Production postponement	Price postponement
	Lower product substitutability	Higher product substitutability

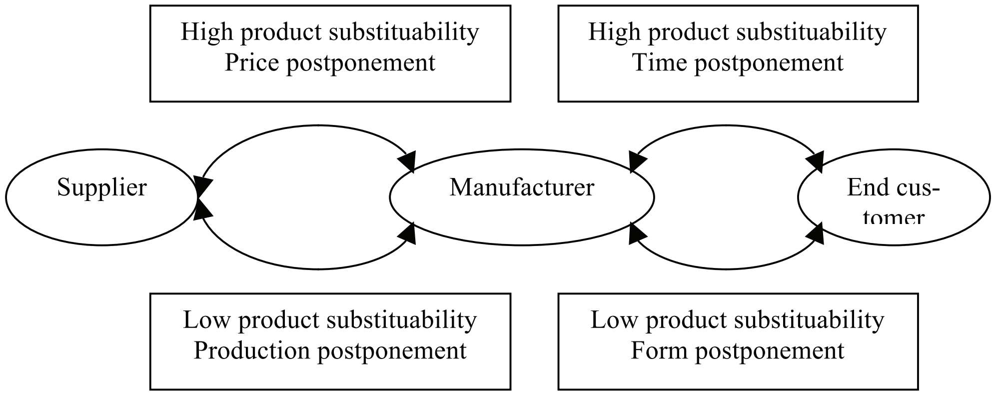

Figure 3. Postponement strategies in supply chain perspective.

Figure 3 shows postponement strategy applications to the supply chain.The figure shows that supply chains are enabled to maximize their benefits in terms of profitability, delivery reliability and inventory level optimization in terms of MC.

3.5.2 RQ 2: How do postponement strategies approach economies of integration for satisfying lead times and delivery reliability?

Paper 3.4.5 supports MC systems by developing procurement strategy for managing information sharing between two suppliers and a buyer. It makes the suppliers' bargaining position over the buyer also improve because each of them can give the buyer more freedom to make more product varieties and promises to the end customer about product availability and delivery lead times. This evidence also encourages the buyer to be more innovative by moving from single mass production to mass customized production by developing a flexible product platform. The positive effects of innovation by collaborating with suppliers are two-fold: first, the buyer and the suppliers obtain higher productivity with higher selling prices so as to support continuous improvement and cost reduction. Second, market positioning is heightened by offering a wide variety of products to the end customer in order to achieve competitive advantage in the market by focusing on customer satisfaction. Additionally, the buyer can avoid suppliers colluding to reduce innovation by updating the market requirements to the suppliers. Consequently, innovation will never stop, because if one supplier cannot follow the new requirement, then the product substitutability degree will decrease, which will make the product platform flexibility also decrease. Thus, core competence in know-how is supported by considering R&D in component modularization and in flexibility by producing a flexible product mix and flexible volume of production so as to reduce delivery lead times. In conclusion, procurement strategy is important to manufacturing strategy by supporting the whole competencies needed to achieve competitive advantage.

Paper 3.4.6 supports MC by investigating how information exchange effects to optimize MC systems. It provides highly reliable information through the application of information technology to increase demand visibility. It can also encourage the supplier to produce exactly what the manufacturer wants, since he or she must ensure the demand information validity. Thus, information exchange also has effect on procurement strategy by managing the supply chain through the supplier´s relationship with the manufacturer.In conclusion, information flows is important to MC systems to achieve competitive advantage in terms of promised lead times and minimum total costs.

Paper 3.4.7 supports RQ 2 by presenting product platform commonality as a source of competitive advantage. The motivation is that commonality degree supports product mix and volume flexibility, which effect on manufacturing capability (Zhang et al, 2003). Furthermore, in terms of supply strategy, the mutual impact between the manufacturer and supplier production quantity and inventory decisions creates competitive advantage. This paper concludes that inventory and production benefits go to those who can optimize the information exchange effect on lead-time reduction, because of high product commonality. Thus, a combination of production quantity and inventory decisions and product commonality decisions supports strategic flexibility in terms of the supply chain by customizing product at least in terms of cost (production and inventory) through achieving high product platform commonality to improve production flexibility.

Paper 3.4.8 combines the three contributions above (papers 3.4.3 to paper 3.4.7) by developing them into a new form of advanced planning and scheduling (APS). Furthermore, this paper gives additional information to the ASDN model in order to develop further in the area of sourcing decision, inventory allocation and promised lead times to achieve capability in product mix and volume flexibility and deliver customer satisfaction (Zhang et al, 2003).

4 THE AUTHOR´S CONTRIBUTION

One important result is that this dissertation places postponement in a more centrally important position in MC systems. Moreover, a clear division between postponement strategies will enable decision makers to decide not only to apply postponement the production process but also in product development by matching the structuring postponement strategy to fit the product substitutability degree and to manage economies of scale in the supply chains (Paper 3.4.3 and 3.4.4).

The present study contributes to existing knowledge of MC by investigating gaps in MC study.This research mentioned that strategic thinking on hedging against supplier opportunistic actions is useful in order to maximize supply flexibility by reducing supply uncertainty through reward and punishment.Reward and punishment in this dissertation (Paper 3.4.5) represents strategic moves on threat and promises by giving punishment and reward. Furthermore, Paper 3.4.5 proves that reward and punishment will never disadvantage the firm since both the supplier and the firm will receive low payoffs for higher supply uncertainty.

This dissertation contributes to existing knowledge in MC by placing marketing strategy as a newly added strategy with competitive strategy (Watts et al, 1995) in supporting MC as a competitive strategy (Boynton et al, 1993). The motivation is that since postponement strategies are an enabler for MC, therefore marketing as the first area for postponement strategies (Alderson, 1950) should be included in the decision making process.Furthermore, the trend in MC nowadays - personalization (hereafter called customerization) is intensified in the area between marketing and end user (Vesanen, 2007; Kumar, 2008). This dissertation proposes customer co-creation by linking it to manufacturing, procurement and distribution strategy so as to extend end user involvement in the order fulfillment process. This dissertation emphasizes the importance of postponement as a marketing strategy in meeting MC vision and for achieving competitive advantage by promising lead times and delivery reliability to tie customers in to the the entire organization (Paper 3.4.7). Thus, marketing involvement in supporting MC cannot be avoided anymore in providing customers with anything they want: profitably, any time they want it, anywhere they want it, and any way they want it.

Another contribution to SCM is that of synchronized supply (Paper 3.4.6), which represents the importance of information sharing between the buyer and the supplier. A special form of response analysis, which considers the level of product platform commonality, is used to describe the importance of information sharing to encourage more integration of supply chains by exhibiting the lead times and inventory level reductions (Paper 3.4.6). The contribution of this dissertation compared to previous literature (Towill, 1996; Wilkner et al, 2007) is the incorporating of mass customization enablers (component commonality and postponement) within built to order supply chains. Paper 3.4.6 shows that a higher level of information sharing increases manufacturer credibility.

The papers that compose this dissertation discuss MC from different perspectives by presenting different problem examples. However, all of the papers focus on how to think of MC strategically by considering the industrial competition perspective to achieve competitive advantage. Finally, in order to extend the applicability of this dissertation, papers 3.4.5, 3.4.6 and 3.4.7 support Advanced Planning and Scheduling (APS) for creating an Agile Supply and Demand Network (ASDN).The methodology was different to previous APS, while the proposed APS emphasizes SCM efficiency by proposing collaboration as a means of competitive advantage in mass customized industry (Book Chapter).

Below is the model for MC as a competitive strategy.

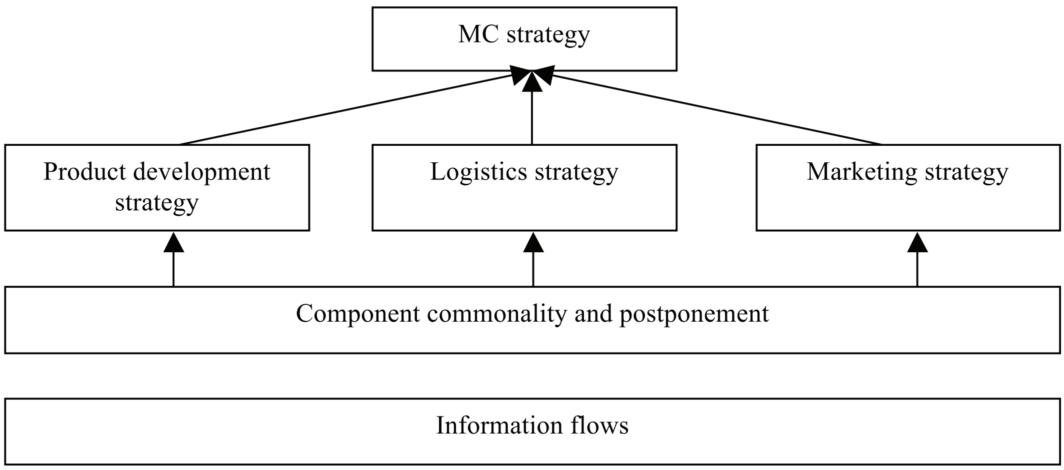

Figure 4. Model for MC as Competitive Strategy.

Figure 4 depicts an MC strategy framework for achieving competitive advantage. Deployment of the MC area into product design, logistics, and marketing strategy includes a wide area such as supply, manufacturing, transportation and warehousing. All of these strategies are enabled by the application of postponement and component commonality strategies.In this figure component commonality supports postponement strategies by providing sufficient flexibility in terms of manufacturability and deliverability. Finally, information flows enable the building of postponement strategies in the perspective of the global supply chain (Van Hoek, 2001).

Table 6 shows the publications and their contribution to supporting the proposed new concept of postponement strategies structure.

Table 6. Publications and their contributions.

Paper title	Novelty	Results
International Journal of Information systems and Supply Chain Management "Dynamic price and quantity postponement strategies"	Dynamic price and quantity postponement as forms of MC systems	Price postponement can be used for developing economies of scale to exploit fixed costs at higher product substitutability, and production postponement at lower product substitutability.
Operations and Supply Chain Management: an International Journal "Time and form postponement strategies under dynamic behavior of demand"	Time and form postponement strategies as forms of MC systems	Time postponement can be used for developing economies of scale to exploit quantity discounts at higher product substitutability, and form postponement at lower product substitutability.
International Journal of Applied Management Science "Strategic Thinking in Supply and Innovation in Dual Sourcing Procurement"	Strategic thinking for managing supply contract between buyer and two suppliers	The results show that it is possible for suppliers to be involved at a higher level of cooperation by considering rewards and punishment from the buyer, which means it is possible to apply multi-sourcing to strategic items
International Journal of Industrial and Systems Engineering "Designing supply chain by coordinating manufacturing process and product development process"	Developing new commonality index and strategic inventory allocation according to 100% guaranteed lead times	The results show that customer co-creation is possible together with supply chain optimization

(Table 5 continued)

Journal and Paper title	Novelty	Results
International Journal of Procurement Management "Built to order supply chains: Response analysis with control model"	A control system model of "Built-to-Order Supply Chain" includes product commonality and response analysis in the simulation model.	The results show that a higher product commonality degree gives more opportunity for quick response built-to-order supply chains, which are managed by feedback control, and at the same time to possibly mitigate supply violation by applying threat and incentive
Book Chapter "Value chain reengineering by the application of Advanced Planning and Scheduling (APS)"	A comprehensive study of APS from the supply chain point of view by considering Agile Supply Demand Networks	APS can be linked to ASDN and some future research directions are exploited for further developing ASDN

5 MODEL VALIDATION

The ultimate goal of model *validation* is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the modeled system, and makes the model actually used.

There was an earthquake in September 1999 in, where the situation made Dell changed its product configuration and price levels (Lee, 2004). Paper 3.4.3 concludes that a highly substitutable product is appropriate for price postponement. The validation for Paper 3.4.4 refers to modularization in HP (Feitzinger and Lee, 1997) in power supply and postponing the assembly of the product. The validation for Paper 3.4.5 refers to contrasting the case of Nokia andEricsson in March 2000, when a Phillips facility in Albuquerque, New Mexico, went up in flames. The plant made radio frequency (RF) chips, key components for mobile telephones for both Scandinavian companies.When the fire damaged the plant, Nokia's manager quickly carried out design changes and contacted back-up sources from two suppliers in Japan and the United States by making a modular product platform. Conversely, Ericsson was unable to hedge against this emergency because it did not prepare for a dual sourcing strategy with the result that they lost sales.

Validation for Paper 3.4.6 also comes from Lee (2004) by taking an example from the Taiwan Semiconductor Manufacturing Company (TSMC), which by giving suppliers proprietary tools, data and models design and engineering changes can be made accurately and quickly. An example from Cisco further enhances the validity in that the company recently created an e-hub, which connects suppliers and the company via the Internet. This allows the firms to share information in terms of supply and demand data on a real time basis. Thus, the case of Cisco validates Paper 3.4.6 by supporting the information sharing idea.

Validation for Paper 3.4.7 comes from Lee and Billington (1995). The supply chain for HP's product contains manufacturing, R&D, and sales and service where fill rate improvement was efffected by applying inventory network optimization. This case validates Paper 3.4.7 by moving from inventory modeling to manufacturing and distribution modeling through product and process redesign.

Validation for Paper 3.4.8 comes from Agile and Supply Demand Networks (ASDN). Paper 3.4.8 corroborates papers 3.4.3 to 3.4.7 by creating advanced planning and scheduling (APS) re-engineering for improving fill rate and minimizing inventory level.

The following sections explain in detail each analytical model validation by considering its applicability and feasibility.

5.1 Dynamic Price and Quantity Postponement Strategies (Paper 3.4.3)

The paper discusses price and quantity postponement under the dynamic behavior of demand. The validity of the analytical models lies in the conclusion part, where it is mentioned that price postponement gives higher profit stability.The analytical model has been tested according to highly varied demand and prices at different levels of product substitutability (higher product substitutability reflects a degree of component commonality). The developed analytical models are valid because at several analysis runs (by applying varied price and demand), the results converge to the same pattern. The results also support previous literature on price and quantity postponement which state that quantity postponement is better to be applied to highly differentiated products (lower product substitutability) by giving a higher component commonality degree.

5.2 Time and Form Postponement Competition under Dynamic Behavior of Demand (Paper 3.4.4)

The developed analytical models follow make to stock (time postponement) and assembly to order (form postponement) cost functions. The cost structures are widely used for inventory management. The validity of the results lie in their consistency with previous concepts of time and form postponement, where time postponement is appropriate for higher product differentiation degree and time postponement for lower product differentiation degree. Furthermore, this paper gives new insight into postponement strategies by introducing competitive analysis for both postponement strategies. This new added analysis makes possible a simultaneous analysis of time and form postponement. Finally, this simultaneous analysis is useful for multi-production lines, where one product is appropriate for time postponement and another product for form postponement.

5.3 Strategic Thinking in Supply and Innovation in Dual Sourcing Procurement (Paper 3.4.5)

The paper discusses the benefit of dual sourcing in terms of the the existence of component commonality. The validity of the analytical models lies in the results part, where a higher degree of component commonality requires higher commitment from the suppliers and the buyer. In many situations, developing a higher component commonality where the manufacturing processes are diversfied in location needs a commitment from the component manufacturers to meet the specification of the buyer, otherwise some manufacturing and testing related problems will appear in the final assembly. Moreover, the application of rewards and punishment are valid for the analytical models since they encourage both suppliers to minimize the supply uncertainty. Furthermore, the effectiveness increases at a higher degree of product substitutability. The results are valid since at higher product substitutability, the suppliers' interdependency is high than that of a lower substitutability degree, which makes the suppliers have a stronger bargaining position over the buyer. Thus it increases the component prices. As a result, supply uncertainty becomes less since the buyer´s customers can easily change their choice from one product to another when the first option is not available.

5.4 Designing Supply Chain by Coordinating Manufacturing Process and Product Development Process (Paper 3.4.6)

This paper discusses the benefit of strategic inventory allocation to give promised lead times and reduce inventory costs to the entire supply chain. The validity of the analytical models can be referred to Graves and Willems (2000), based on a study of camera supply chains. Basically, this analytical model extends the previous model (Graves, 2000) by placing supply and demand uncertainty into the previous model, and relating the inventory allocation problem to component commonality development. The analytical models prove that strategic inventory allocation gives benefit to component commonality strategy by significantly reducing component total costs. If we refer back to another component commonality principle (Collier, 1981; 1982; Jiao and Tseng, 2000), it is mentioned that component commonality depends on the amount of component utilization and its total costs. Thus, the developed analytical models are valid since they give the same results as previous literature: that the application of strategic inventory allocation reduces supply chain total costs as well as increasing the component commonality degree.

5.5 Built-to-Order Supply Chain: Response Analysis with Control Model (Paper 3.4.7)

The paper here discusses the benefit of information sharing in terms of order quantity and inventory level to two levels of built to order supply chains. There are many papers which discuss this area, for instance Towill (1996) and Wilkner (2007). The previous literature excludes the effect of component commonality in information sharing. However, the present dissertation concludes that a higher degree of component commonality positively supports information sharing.The validity of this conclusion comes from everyday operations in supply chains, where a higher degree of component commonality makes the component supplier invest in component inventory to guarantee that supplier delivery lead times are met. We can confront this argument with ABC analysis, which is widely used in accounting.Moreover, higher component commonality reduces production responsiveness, where it also valid since it also reduces the changeover period between one product to another. In conclusion, the developed analytical models support the dissertation concept on postponement strategies by suggesting that higher component commonality degree increases operational stability by using common component for several production lines,and increases delivery reliability by reducing supply uncertainty because more common components are used.

5.6 Value Chain re-Engineering by The Application of Advanced Planning and Scheduling (Paper 3.4.8)

The paper discusses the benefit of economies of integration for global supply chains by using Advanced Planning and Scheduling (APS) and Agile Supply and Demand Networks (ASDN) (Helo et al, 2006). Basically, this paper uses previous results of time and form postponement to decide on the Customer Order Decoupling Point (CODP) (Paper 3.4.4), dual sourcing strategy (Paper 3.4.5), response analysis for built to order supply chain for optimizing total stocks, delivery lead times and product substitutability degree (Paper 3.4.6), and strategic inventory allocation and component commonality strategies for achieving 100% guaranteed lead times. One example from truck manufacturing is taken to illustrate the operability of the proposed analytical models. The validity of the analytical models mostly comes from the future requirement of postponement strategies (Van Hoek, 2001) and supply chain integration and coordination (Staedtler, 2005).The future requirement of postponement strategy is that it gives the required operational flexibility to support supply chain reconfiguration. The proposed analytical models answer this requirement by introducing comprehensive analysis from strategic planning to operational planning by using APS. Furthermore, supply chain integration and coordination are also possible by developing the analytical models through game theory analysis to create acceptable solutions for the inter-related parts in supply chains.

6 CONCLUSION

This study extends previous MC Strategy by shedding new light on competitive strategy. Competitive strategy upgrades the level of MC discussion from manufacturing considerations to the wider perspective of procurement, product development and marketing perspectives by drawing attention to the importance of balance between information and physical flows. This importance comes from the reality that in order to customize the process, the firm needs many resources and elaborate systems (Zipkin, 2001). Obviously, finding a balance between this huge investment and MC strategies according to product and process capabilities is essential.

In terms of managing economies of scale in the supply chain, it is important to apply different postponement strategies with different type of supply and demand contracts. If the product substitutability is high, then a buyer (manufacturer) needs to divide its products costs into two parts. The first part is subject to the component supplier by applying price postponement at fixed order quantity to minimize the order receivingand transporting costs. The second part is subject to the final customer by applying time postponement to gain advantage from economies of scale to exploit quantity discounts (Paper 3.4.3). Conversely, if the product substitutability is low, then a buyer (manufacturer) needs to divide its product costs also into two parts. The first part is subject to the component supplier by applying production postponement at fixed order quantity to minimize the order,receiving and transporting costs. The second part is subjected to the final customer by applying form postponement to gain advantage from economies of scale to exploit quantity discounts (Paper 3.4.4). The combination of the two postponement strategies at a certain product substitutability level maximizes the profitability of the supply chain.

In terms of the tactical decision level, it is important to consider this level aligned to the previous strategic level. In other words, any tactical decision should consider the competitiveness of the products. Competitiveness at this stage is focused on the whole products of the firm that share the same functions and considering their profitability. The effect of this decision is that the firm must establish not only core competence analysis, but also product platform commonality in order to build a competitive strategy for the product family.

In supportings competitive strategy, a supplier evaluation by considering make or buy decision and dual sourcing strategy also helps a manufacturer to maintain competitiveness in supply strategy (Paper 3.4.5). In other words, creating competitiveness through purchasing strategy creates stability and competitiveness in the supplier pool (Porter, 1980). The leveraging of this situation creates fair competition between the suppliers, and possibly produces strategic moves among the suppliers through reward and punishment as forms of threats and promises (Paper 3.4.5). Furthermore, creating competition among suppliers also promotes standardization, so that it also undercuts the erection of switching cost, stabilizes and maintains the competitiveness of the supplier pools, achieves an optimal degree of vertical integration, allocates the number of purchases among qualified suppliers and creates maximum advantage with the chosen suppliers (Porter, 1980).

In terms of logistics strategy, information sharing supports competitive strategy by showing that standardization can reduce lead times and inventory level (Paper 3.4.6). This conclusion also undercuts the erection of switching cost by promote standardization among suppliers (Porter, 1980). Leveraging of this attempt ensures the supplier trusts the demand information from the buyer with a high degree of confidence. Control system application shows that information sharing increases the credibility of the buyer and, indirectly, this is the other form of strategic move of the buyer.

In terms of marketing strategy, coordinating the product development processes and manufacturing prices, as well as customizing price and order size, supports competitive strategy of a firm. These supports come from the improvement of the customer involvement degree in product development and increasing customer satisfaction, by improving the firm´s visibility to the customer (Paper 3.4.7). Thus, meeting the customer´s wants more closely than other competitors creates competitive advantage.

In terms of product development strategy, coordinating product development processes and manufacturing prices as well as customizing price and order size supports competitive strategy by improving the customer involvement degree in product development and increasing customer and supplier alignment to the manufacturer (Paper 3.4.8).Thus, it also reduces time to market as well as minimizing information assymetry.

7 FURTHER RESEARCH

One of the issues raised in this study concerns the fact that analytical modeling is the basis for much of the content of the thesis. It would be useful in the future to test the models in a real case study. However, in detail, some of the future research possibilities are listed below:

1. In terms of future research direction, the oligopoly model should be considered for price and quantity postponement development according to future market demand, which is determined by how closely customer requirements are met, so in future the oligopoly model of quantity and price could be replaced with parameters such as inventory and lead times. From this result, a sequence between lead times and inventory could be determined and the outcome would be a decision as to whether agility or efficiency are more important for a company, so that the outcome can be used by top management to formulate their business strategy. Finally, future research should accommodate strategic and tactical level alignment in order to develop comprehensive decision analysis.

2. The analytical model of dual sourcing procurement (Paper 3.4.5) focuses on strategic thinking application in dual sourcing by considering innovation. In terms of future research direction, it would be necessary to investigate the possibility of applying strategic thinking in dual sourcing, where one of the suppliers assumes that the buyer is not the dominant customer. An example of this situation in industry is with computer fan suppliers. The fan is a critical component of the personal computer. If one buyer asks the suppliers to change the design by increasing the speed and reducing the power consumption of the fan, then the fan suppliers will not directly change the design without considering the contribution of the buyer to the suppliers' market share. Thus, it is difficult to attract a stronger supplier to maximize innovation. The possible solution is not only threats and promises, but also the commitment to use the fan in the entire product portfolio. The problem is that dual sourcing allows dual supplier application simultaneously. This is the future research area that should be investigated.

3. The analytical model of information sharing in built to order supply chains (Paper 3.4.7) focuses on symmetrical information sharing between two parties. In terms of future research direction, it would be necessary to investigate the possibility of applying strategic thinking in the model, where the supplier assumes that the buyer is not the dominant customer. Thus, it

is difficult to maintain information security in terms of the buyer's platform design, so that the issue of security can also be raised. This is a future research area that should be investigated.

4. Finally, in considering the "knowledge economy", information sharing should be extended into what is called "knowledge sharing". The difference is that in knowledge sharing, the role of supply chain integration is more dominant than supply chain coordination. Furthermore, in resource based competition, the capability to exploit knowledge inter-organizationally is important for generating agility and enterprise interoperability.Knowledge sharing is not only capable of mitigating the bullwhip effect, but also makes time to market shorter and the product innovation level to increase significantly.

These four future research directions would fulfill the future needs of MC in general. Specifically, postponement strategies are becoming more applicable in MC by producing component commonality at a higher level and allowing information to flow freely along supply chains.

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APPENDIX A.

PAPER 3.4.3:

DYNAMIC PRICE AND QUANTITY POSTPONEMENT STRATEGIES

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ABSTRACT

This paper studies duopolistic competition under dynamic price and production quantity postponement for two differentiable products, which share common components from one supplier at a certain degree of substitution. Both price and quantity postponement is benchmarked according to the Bertrand and Cournot Stackelberg game. In addition, system dynamic is applied to show the long term effect of both strategic decisions (price and production quantity) on profit and against demand uncertainty. The results show that price postponement is appropriate for high modular products (make-to-stock) and production quantity postponement for special orders (make-to-order). The final part of the paper concludes the results and outlines future research directions.

Keywords*: Strategic Planning, Supply Chain Management, Game Theory, Managerial Flexibility, Market Share*

INTRODUCTION

Price and production capacity are two strategic decisions which product managers face over time. Kreps and Scheinkman (1983) showed that if firms choose capacities before engaging in Bertrand-like price competition, then the Cournot outcome is the result if the given capacities are at Cournot levels, or they should be rationed when the capacity cannot meet market demand. Davidson and Doneckere (1986), however, argued against this investigation and showed that the alternative rationing rule can eliminate idle capacity because the players agree to compete at higher equilibrium capacity.

Because the products undertaken by order-based firms are characterized by uniqueness, uncertainty and complexity, however, the Kreps and Scheinkman or Davidson and Doneckere rationing rules are difficult to apply to this type of firm. One reason is that order-based firms are different from mass production-based firms in many respects. These differences extend to their requirements with respect to product substitutability because consumer preferences are diversified among the available brands (Perloff and Salop, 1985). Since a homogenous product gives no options to consumers, most discussions of price or production postponement focus on their appropriateness, depending on the single firm demand uncertainty (Fine and Freund, 1986, 1990; Miegham, 1998; Miegham and Dada, 1999), while the product substitutability effect is often considered exogenous, so that such models may underestimate the benefit of production and price postponement to mass customized products.

The effectiveness of product substitutability degrees has been extensively studied in a large number of contributions (Spence, 1976; Singh and Vives, 1984; Katz and Shapiro, 1985; Perloff and Salop, 1985; Martin S, 1995; Colombo, 2002; Lambertini et al, 2004; Panchal et al, 2007). Some of them, for example Singh and Vives (1984), analyse the dominant strategy between price and quantity predetermined contract in a differentiated duopoly. On the other hand, Cellini and Lambertini (2002) and Lambertini and Mantovani (2004) investigated a long term join venture in Research and Development (R&D) to optimize the product differentiation degree (hereafter called product substitutability degree) of cooperating and non-cooperating firms according to the competition, according to Cournot.

With respect to previous efforts in product substitutability degree investigation, so far, few serious attempts have been made to investigate the effect of product substitability degree on price and production quantity dynamics instead of their values at any given of time. However, the dynamic property is important with regard to the optimum price and quantity postponement decision, at which every player has no reason to change his price or production quantity decision. Our effort in this paper broadly follows Singh and Vives (1984), except that we take into account the possible effects of long term price and production quantity postponement strategic decision, resulting from the presence of product substitutability, as a result of common product platform application, and Dr. C.F Ross (1925) in terms of the possible effect of change in the rate of price and production quantity resulting from demand variety. In particular, unlike most of the existing literature on repeated games under product differentiation, we explicitly model those demand uncertainty effects which affect firms' production quantities as well as prices.

In addition to recent literature, the open loop water tank analogy is a special case of price and production postponement for a continuous product substitutability distribution. This new approach is quite different to previous methods in the differentiated duopoly game (Singh and Vives, 1984) or price and production postponement (Fine and Freund, 1986, 1990; Miegham, 1998; Miegham and Dada, 1999), where the decision is assumed to depend merely on the price or production quantity at any given time, without considering whether the price or production quantity is increasing or decreasing at this time. Even this new approach also quite different to Lambertini et al (2002), where competition is assumed under Cournot solely, without considering production quantity competition under the Bertrand game or impact of price postponement to capacity and flexible investment (Biller et al, 2006), where price postponement is used to balance between available supply and demand, without considering time the demand is increasing or decreasing at this time or Birge et al (1988) where price and capacity postponement is used to substitutable product, without considering the demand variety. Indeed, in order to comprehend price and production quantity postponement application appropriately, we compare price and production quantity postponement in terms of their profitability at several product substitutability degrees and under varied demand.

The following sections first introduce related literature on dynamic analysis in competition, product substitutability in duopoly competition and the research area of this paper (Related Literature Section). Methodology section is started by price postponement analysis using the Cournot game model, which continues with production quantity postponement (hereafter called production postponement) by applying the Bertrand game model. Discussion section presents and discusses the simulation results, which are concluded in Conclusion and further research, which explores the information behind the simulation results in the previous section and discusses some future research opportunities.

RELATED LITERATURE

Dynamic analysis in competition was firstly presented by Dr. C.F Ross (1925) and it was rediscussed further by Smithies and Savage (1940). Dynamic analysis was used to represent a decision maker who intends to plan his capacity in advance according to the present situation. It is clear that production capacity needs long term planning and the paper addresses a problem of two competitors adapting to a new demand function with the goal of profit stability in the future. In contrast, Dudey (1992) argues against both papers by introducing dynamic edgeworth-bertrand competition in order to solve dynamic competition under capacity constraint, which causes Nash equilibrium inexistance. The Dudey model assumes that customers come to the market at different times and the firm's price can be reset at any time with an opportunity that at least one of the duopolists can sell all the units it is able to produce. When this game is a duopoly, the payoff function of each firm maps the duopolists' strategy choices into the firm's total expected profit. Even though the Dudey model used dynamic pricing, this model presents price as a short term decision, which can be changed at any time. However, our model posits price and production quantity as two strategic decisions, which are fixed at a certain finite time in order to handle demand change.

Similar to the approaches of Smithies and Savage (1940) or Dudey (1992) on price and quantity, Singh and Vives (1984) focus their analysis on flexible capacity / price appropriateness to hedge against predetermined price/quantity contracts. Their analysis adapts to a new demand or price after making a price or delivery quantity contract formerly under the absence or presence of product substitutability degree. In contrast to that paper, we contribute to this literature by adding dynamic behavior onto the Singh and Vives (1984) duopoly model by analyzing the impact of demand uncertainty on the firm´s profitability by applying dynamic price or production quantity postponement strategy. In particular, the Cournot duopoly model (Singh and Vives, 1984) is a special case of price postponement and the Bertrand duopoly model a special case of production postponement. In conclusion, our contribution is focused on the dynamic analysis of the Singh and Vives model (1984). With a different objective to the Smithies and Savage (1940) or Dudey (1940) models, this paper uses dynamic analysis to investigate the price and production quantity postponement effect on supply chain profit.

METHODOLOGY

Suppose now that two firms can agree on only two types of contracts: the price contract and quantity contract. Singh and Vives (1984) use predetermined price or quantity to supply customer demand at any levels. From this point on, we refer our discussion on price postponement as make-to-stock and production postponement as make-to-order. The reasons are that the price postponement manufacturer holds inventory at his final manufacturing stage and the price is determined after customer demand (hereafter called production quantity) is known, while the production quantity postponement manufacturer never produces any products before an exact order specification based price is known. To focus the discussion, this paper uses Singh and Vives demands and their reverse function by assuming that both products are perfect substitutes. The effects of this assumption are products having a sticky price and quantity, which enforces equal cost application. Sticky price and quantity in this case are a situation where both duopolists have no reason to change their decisions on price or production quantity. To gather general understanding for this concept, both postponement concepts will be discussed separately and then the general concept will be developed. Beforehand, some notations are introduced to guide the following discussion.

Notations

Q	Equilibrium quantity
p_1	Retailer 1 price
p_2	Retailer 2 price
q_1	Retailer 1 quantity
q_2	Retailer 1 quantity
c	Supplier price
γ	Product substitutability degree
a	Maximum price
b	Retailer 1 and 2 total production capacity
π_p	Supply chain profit according to the Cournot game
π_q	Supply chain profit according to the Bertrand game

Model Description for Price Postponement

In this model we consider a Cournot duopoly model (see Cournot, 1960; Gibbons 1992) with price function for retailers given by

$$P(Q) = a - Q \qquad (1)$$

Where Q is total production quantity from both retailers (retailer 1 and 2). In the Cournot game firms choose their own quantity to maximize their profit by taking their opponent's quantity as a given, and in the Bertrand game they choose their price to maximize their profit by taking their opponent's price as a given. This means that they are going to sacrifice price in the Cournot game and quantity in the Bertrand game. We thus propose a methodology to avoid price sacrifice by applying the Dynamic Stackelberg game just after a predetermined quantity or price game.

To illustrate, we suppose two firms can make two types of contracts, namely price and quantity contracts. If the firms choose price postponement, then they must hedge against production fluctuation as a result of demand uncertainty. If the firms choose production quantity postponement, then they must hedge against price fluctuation. Firms first choose what type of contract and afterwards they compete on the chosen type of contracts by considering selling and material prices. Restricting attention to the subgame perfect of this two stage game, we shall see that if firms choose price postponement, then predetermined quantity is used to optimize the selling price, where it is finally used by the supplier to optimize his material price. Both retailers do not have any benefits by shifting from their optimum point, while the supplier also does not have any reasons to threaten retailers. From this point on, the game is started from stage 2, where both retailers decide their capacity.

Stage 2 Retailers decide their capacity according to the Cournot game

In this stage retailers 1 and 2 simultaneously choose production quantity to maximize their profit, taking supplier price (c) as a given. That is, maximize $q = q_1 = q_2$, where q is a function of c, derived from profit equation below

$$\underset{q_2}{Max}\pi = (a - q_1 - q_2 - c)q_2 \tag{2}$$

By assuming equal costs function (c) and incorporating a degree of product substitability (γ), so (2) can be modified according to Cournot duopoly inversion (see Singh and Vives, 1984) as follows

$$\underset{q_2}{Max}\pi_2 = \left(\frac{a}{1+\gamma} - \frac{1}{1-\gamma^2}q_1 - \frac{\gamma}{1-\gamma^2}q_2 - c\right)(q_2) \tag{3}$$

The first order condition (FOC) for supplier-1 is then

$$\left(\frac{a}{1+\gamma} - \frac{q_1}{1-\gamma^2} - 2\frac{\gamma.q_2}{1-\gamma^2} - c\right) = 0 \tag{4}$$

Similarly, the FOC for supplier-2 is

$$\left(\frac{a}{1+\gamma} - \frac{q_2}{1-\gamma^2} - 2\frac{\gamma.q_1}{1-\gamma^2} - c\right) = 0 \tag{5}$$

We can solve (4) and (5) simultaneously to be

$$q_2 = q_1 = \frac{\left(1-\gamma^2\right)\left(\frac{a.(1-2.\gamma)}{(1+\gamma)} - c.(1-2.\gamma)\right)}{1-4.\gamma^2} \tag{6}$$

We see it slope down for the increasing of material price (c). This relationship also supports the subgame perfect principle with both retailers taking the material price as given and at the same time the supplier maximizes his profit by taking the retailer´s order quantity as given.

Since two-stage games can solve only individual contracts,, this game uses production quantity and price contracts consecutively. The reason is we assume that the products are perfect substitutes. We shall use this upcoming section to make price contracts for both retailers.

Stage 1 price decision

Singh and Vives (1984) use a two-stage game, in which the firm will have to supply the amount the consumers demand at a predetermined price or quantity. This paper applies a similar principle to Singh and Vives (1984), except that we take into account the price or quantity at infinite time in order to optimize the postponed decision resulting from the presence of long term price or production quantity contract. Different to the Stackelberg game of Ferstman and Kamien (1987) ,Fujiwara (2006) or Clemhout et al (1971), this stage is developed by using time and Laplace domain dynamics, which describes price or quantity response against production quantity or price contract decision. These approaches describe a natural response instead of optimal setting, even though we can guarantee their optimality by assigning optimal production or price quantity. This approach is described as follows

$$\dot{p}(t) = \left(\frac{a}{1+\gamma} - \frac{1}{1-\gamma^2}q_1 - \frac{\gamma}{1-\gamma^2}q_2 - p(t)\right); p(0) = p_0 \tag{7}$$

By assuming sticky quantity and prices, then (7) can be reformulated as

$$\dot{p}(t) = \left(\frac{a}{1+\gamma} - \frac{1+\gamma}{1-\gamma^2}q - p(t)\right) \tag{8}$$

Equation (8) describes price dynamics, which is caused by quantity decision. This paper uses the analogy of water level in a tank: for instance, if production quantity is increased then price is automatically reduced. The same case applies in a water tank: if the water outflow is increased then the tank level is automatically reduced.

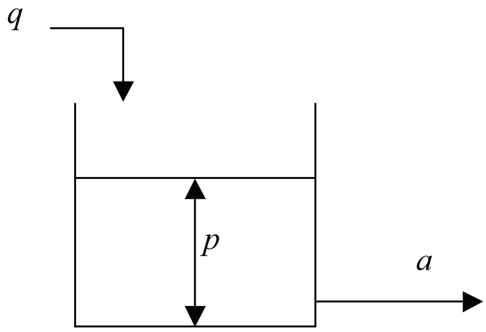

Figure 1 Dynamic Price Postponement

Figure 1 is taken from waterflow analogy. Inflow describes a steady state quantity and it is assumed to be constant. Outflow describes the actual demand and it is assumed to be dynamic. The price decision naturally follows according to demand. We can rearrange (8) according to

$$\dot{p}(t)+p(t)=\frac{a}{1+\gamma}-\frac{1+\gamma}{1-\gamma^{2}}q \tag{9}$$

Equation (9) is a first order price dynamics. By manipulating it into time domain price dynamics, Laplace domain price dynamics is obtained as follows

$$\frac{p(s)}{q(s)}=\frac{-(1+\gamma)}{(s+1)(1-\gamma^{2})} \tag{10}$$

Equation (10) is formed by excluding $\left(\frac{a}{1+\gamma}\right)$ in (9) and a step response (1/s), which represents demand variety, can be attached to (10) so that we have $\frac{p(s)}{q(s)}=\frac{-(1+\gamma)}{s.(s+1)(1-\gamma^{2})}$. This Laplace domain is finally converted to time domain price dynamics as follows

$$p(t)=\frac{a}{1+\gamma}-\left(1+\frac{(1+\gamma)}{1-\gamma^{2}}.e^{-.t}\right).q(t) \tag{11}$$

At a steady state, the price function can be simplified to be $p=\frac{a}{1+\gamma}-q$

The result of equation (10) is used by the supplier to set his selling price to retailers as the following relationship

$$\max_{c}\left(b - p_1 + \gamma p_2\right).c \tag{12}$$

By combining (6) and (12) then we have

$$\max_{c}\left(b + (\gamma - 1)\frac{a}{1+\gamma} - .\frac{\left(1-\gamma^2\right)\left(\frac{a.(1-2.\gamma)}{(1+\gamma)} - c.(1-2.\gamma)\right)}{1-4.\gamma^2}\right).c \tag{13}$$

$$c = \frac{1-4.\gamma^2}{2(1-2.\gamma)\left(1-\gamma^2\right)}\left(\frac{\left(1-\gamma^2\right)\frac{a.(1-2.\gamma)}{(1+\gamma)}}{\left(1-4.\gamma^2\right)} + (1-\gamma)\frac{a}{1+\gamma} - b\right). \tag{14}$$

Equation (14) describes a strong relationship among product substitutability (γ), retailer´s quantity and supplier price setting. We can see that supplier price is a concave function of product substitutability (γ).

Model Description for Production Postponement

Consider a Bertrand duopoly model with price function (see Gibbon, 2002) for retailers given by

$$Q = b - p_i + \gamma.p_j \tag{15}$$

Where p_i and p_j is price of product 1 and 2.

In the Bertrand game firms choose their own price to maximize their profit by taking their opponent’s price as a given. We thus propose a methodology which is similar to the previous Cournot game, except that we take into account the quantity at infinite time in order to optimize the postponed decision resulting from the presence of long term price contract.

This game decides the equilibrium price first before capacity and it can be described as follows

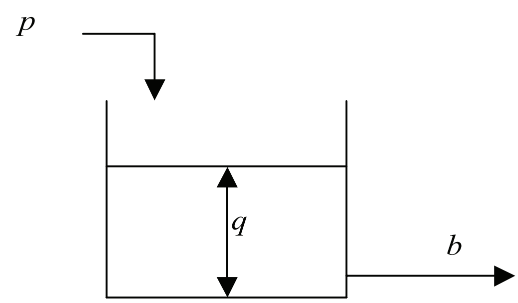

Figure 2 Dynamic Production Postponement

Figure 2 is taken from waterflow analogy. Inflow describes a steady price state and it is assumed to be constant. The managerial price related decision is located at the output and it is assumed to be dynamic. Quantity automatically follows, whatever the price pattern, as the water level is also controlled by its flow in a storage tank. These two situations are identical to one another.

Stage 2 Retailers decide their price according to the Bertrand game

In this stage, retailers 1 and 2 simultaneously choose the product price to maximize their profit, taking the supplier price (c) as given. That is, maximize $p = p_1 = p_2$, where q is a function of c, derived from the profit equation below

$$\max_{p1}(b - p_1 + \gamma.p_2)(p_1 - c) \tag{16}$$

The first order condition is

$$b - 2p_1 + \gamma.p_2 + c = 0 \tag{17}$$

Similarly, the FOC from the second product variant is

$$b - 2p_2 + \gamma.p_1 + c = 0 \tag{18}$$

Solving these two equations simultaneously, one obtains

$$P_2 = P_1 = \frac{(\gamma + 2)(c + b)}{(4 - \gamma^2)} \tag{19}$$

We see it slope up for the increasing of material price (c). This relationship supports the Bertrand principle, where both retailers and suppliers maximize the price by sacrificing production quantity.

Since two-stage games can solve only an individual contract, this game uses product price and quantity contracts consecutively. The reason is we assume that the products are perfect substitutes.

Stage 1 Leader decides his own profit function

At the first stage we can find the material price by optimizing supplier profit function as

$$\max_{c}(b - p_1 + \gamma p_2).c \tag{20}$$

Find c by insert (19) into (20), so we get

$$\max_{c}\left(b+(\gamma-1)\frac{(\gamma.c+\gamma.a+2.c+2.a)}{(4-\gamma^{2})}\right).c \tag{21}$$

$$c=\frac{(4+\gamma-2).b}{(1-\gamma)(2.\gamma+4)} \tag{22}$$

Equation (21) describes a strong relationship among product substitutability (γ), retailer quantity and supplier price setting. We can see that supplier price is a concave function of product substitutability (γ). We shall use this upcoming section to make a quantity contract for both retailers.

Capacity decision

In the same manner as price postponement, quantity postponement uses time and Laplace domain dynamics as follows

$$\dot{q}(t)=(b-p_1+\gamma.p_2-q(t));\, p(0)=p_0 \tag{23}$$

Equation (23) describes quantity dynamics, which is caused by pricing decision. This paper uses the analogy of water level in a tank as well as the price postponement model (see Figure 2)

By assuming sticky price and quantity, then (23) can be rewritten as

$$\dot{q}(t)-q(t)=(b-(1-\gamma)p) \tag{24}$$

Equation (24) is a first order price dynamics, which describes firm effort to achieve optimum production quantity level against pricing strategy. By manipulating it into time domain price dynamics, Laplace domain price dynamics is obtained as follows

$$\frac{q(s)}{p(s)}=\frac{-(1-\gamma)}{(s+1)} \tag{25}$$

Equation (25) is formed by excluding b in (24) and a step response (1/s), which represents demand variety, can be attached to (25) so that we have $\frac{q(s)}{p(s)}=\frac{-(1-\gamma)}{s.(s+1)}$. This Laplace domain is finally converted to time domain quantity dynamics by incorporating b as follows

$$q(t)=b-\left(1+\frac{1}{1-\gamma}.e^{-k.t}\right).p(t) \tag{26}$$

Equation (26) is a quantity postponement as a result of price predetermined contract.

DISCUSSION

Studies on price and production postponement have been able to shed light on the supply chain as a dynamic system. In addition, they have underscored the importance of such long term stability as values, meanings and commitments and paved the way for more elaborate research on interface between supply chain and revenue management.

What happens if both firms choose the price contract? In that case firms choose production quantity to maximize their profit, taking p as given. This yields the profit reaction which corresponds to the Bertrand reaction. Notice that it is downward sloping for the increasing of product substitutability degree. The reverse action is shown for production quantity contract, where firms choose price to maximize profit. These discrepancies inform us that price postponement is an appropriate choice for higher substitutability degree (see Figure 3).

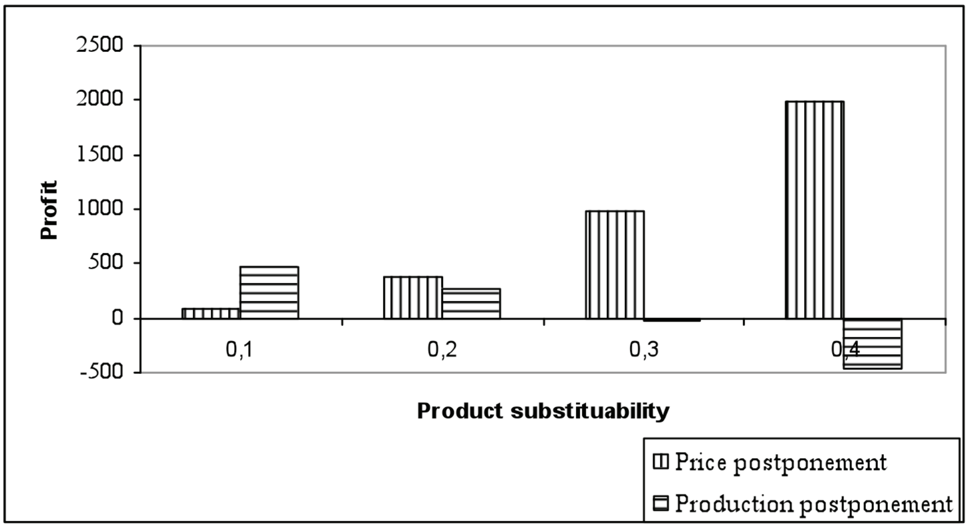

Figure 3 Profit from price and production postponement as a function of product substitutability degrees

To examine the case with erratic demands, suppose firms strictly predetermine their price or quantity settings, which is strictly revised in their profitability. Now if we randomize a or b value to represent demand variety, then we get $\pi_{(p)}$ or $\pi_{(q)}$ as a function of q, p and γ; hence, the results can be drawn as follows

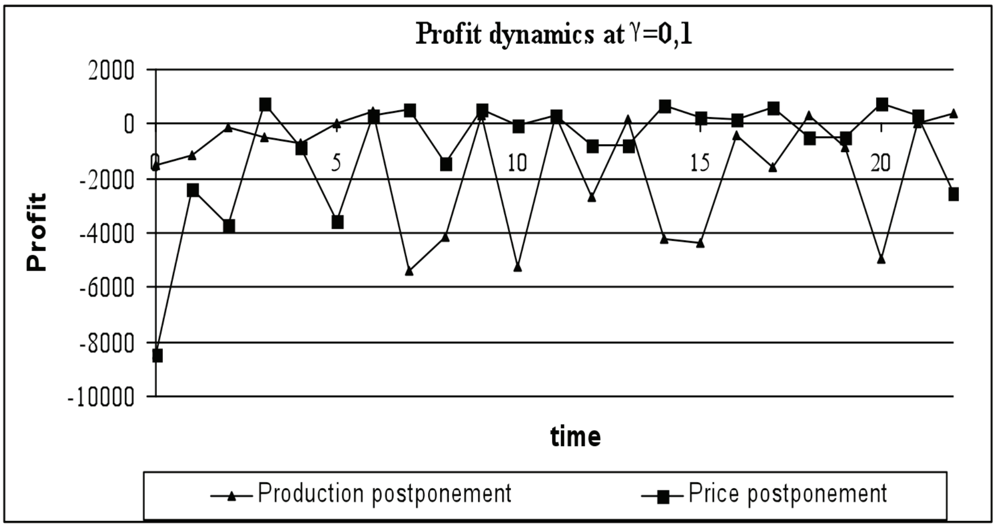

Figure 4 Profit dynamics at γ=0,1 for price and production postpone-

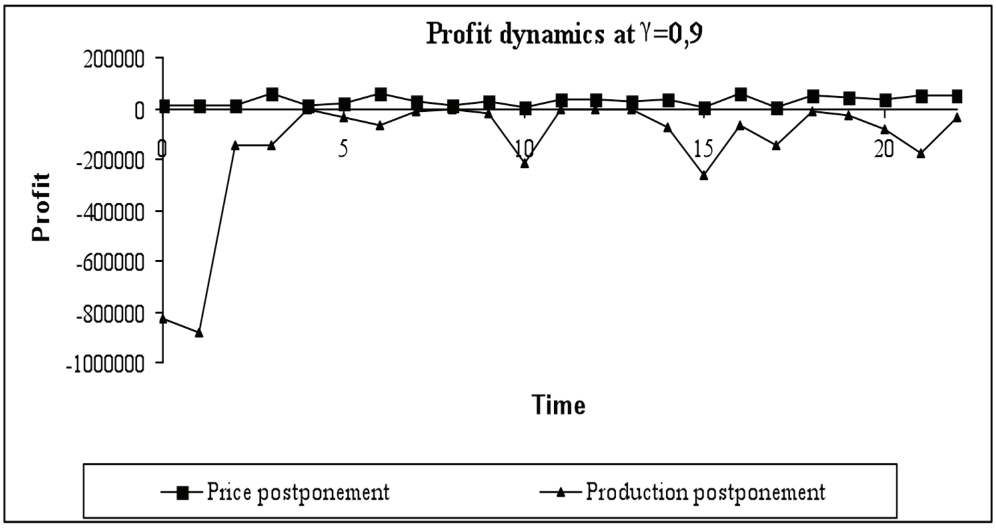

Figure 5 Profit dynamics at γ=0,9 for price and production postponement

Figure 4 and 5 clearly show that price postponement is more stable at varied demands, which also shows further that price postponement gives higher stability at higher product substitutability degrees. These results again ensure that price postponement reaction is appropriate at higher compatible products.

We know that profit stability is a common goal of price and production quantity contracts. High profit stability ensures two firms can cooperate without worrying about any losses. Below is a comparison between two postponement types, which is gathered by finding profit at different price or quantity settings. Now if we measure their deviation from optimum profit value (replace q or p by our own assumption), then we get $\pi_{(p)}$ or $\pi_{(q)}$ as a function of q, p and γ. Benchmarking them against optimal value, the results can be exhibited as figure 6 below

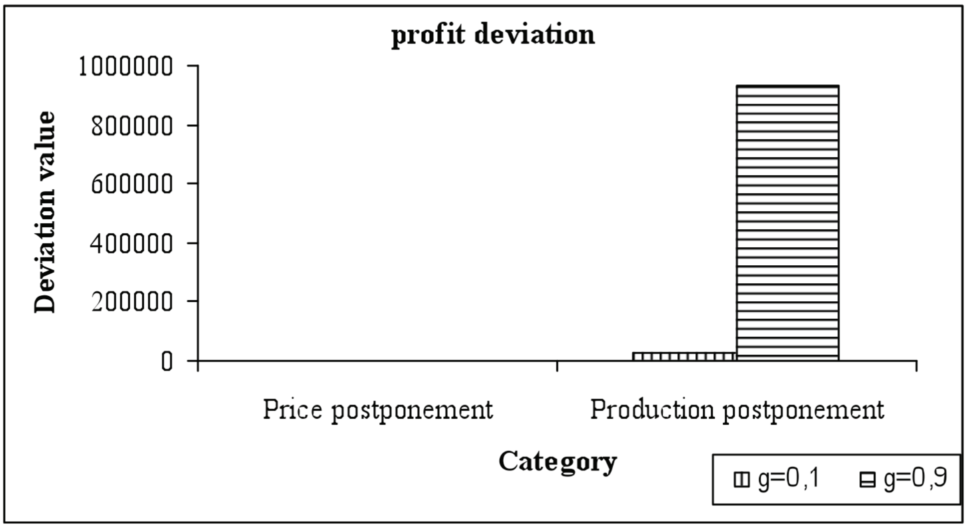

Figure 6 Profit deviation at γ=0,1 and 0,9 for price and production postponement

In addition to the managerial implication, price postponement is also significantly superior to production postponement from the customer service level point of view (see Figure 7). That figure shows that price postponement can cover market demand at a higher level than production postponement. This result supports the managerial policy of product commonality, where price can be determined later after final customization is completed.

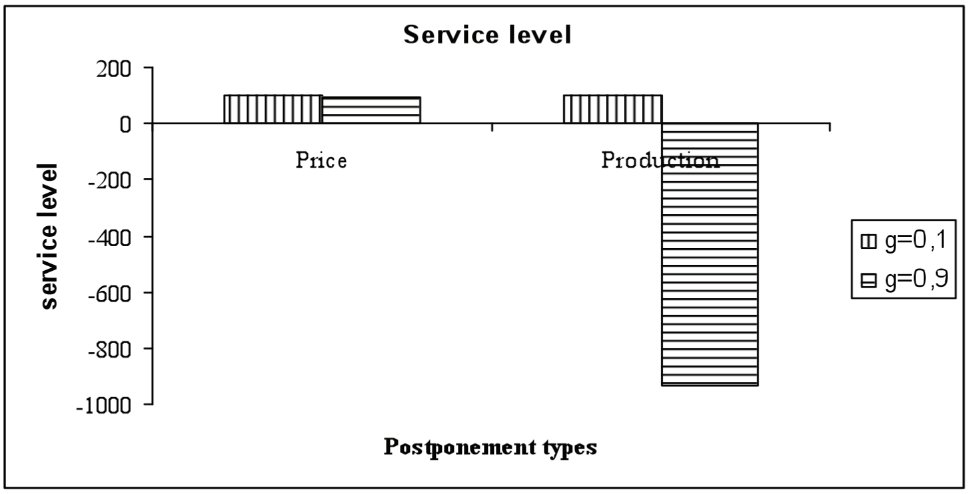

Figure 7 Service level at different postponement types

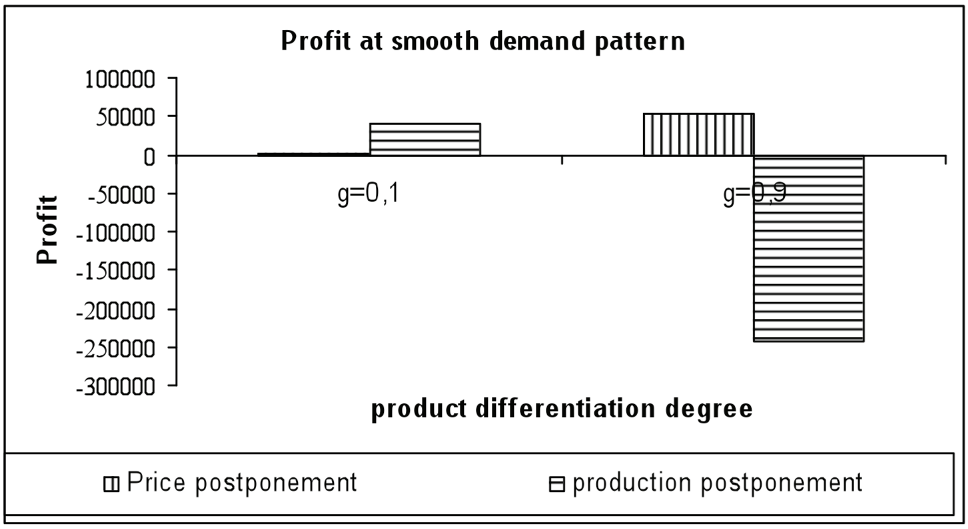

Figure 8 Profit level at smooth demand pattern

What happens if demand pattern is smoothed? In that case, firms choose production postponement to maximize their profit, taking p as given (see Figure 8).

Furthermore, price postponement is still superior over production postponement at a higher product substitutability degree. This result once more supports the view that make-to-order (production postponement) is only appropriate to highly unique products. The reverse result is shown for price postponement, where firms develop a common platform to maximize profit. Those discrepancies also inform us that price postponement is an appropriate choice for higher substitutability degree.

CONCLUSION AND FURTHER RESEARCH

This paper revisited the Singh and Vives model on price and production postponement by considering the dynamic behavior of demands. We may summarize the results derived from the model, as follows.

1. Price postponement is superior to production postponement at many respects. This type of contract guarantees profit stability and at the same time supports the product standardization effort

2. Price postponement is also a dominant strategy for substitutable products. This conclusion is at odds with the previous Singh and Vives conclusion (Singh and Vives, 1984). This discrepancy is caused by the Singh and Vives model perhaps assuming that in Bertrand price-like competition, the quantity setting will avoid both firms having to reduce their production quantity further. On the contrary, this paper assumes sticky prices and quantities, where it pushes both firms to cooperate at higher levels. By sticky prices and quantities, this paper is more appropriate for common platform based products instead of two widely differentiated products.

3. Production quantity postponement (make-to-order) is a dominant strategy for highly differentiable products. This conclusion supports the article of Miegham and Dada (1999), who discusses postponement strategies differentiation according to their applicability.

The dynamic behavior analysis in this paper helps decision makers to decide their long term postponement policy with regard to their manufacturing types, namely make-to-stock or make-to-order. The analysis results also support both modularity and customization principles in mass customized products, where decision uncertainty can be reduced by making closer customer order decoupling, point to sales point. This paper suggests that product developers design common platform products and decide the price according to customer specific requirements.

In terms of future research direction, the oligopoly model should be considered for development according to future market demand, which is determined by how close customer requirements are met, so in future the oligopoly model quantity and price can be replaced with some parameters such as inventory and lead times. From this result, a sequence between lead times and inventory can be determined and the outcome will be a decision about whether agility or efficiency is more important for a company, so that the outcome can be used by top management to compose their business strategy. Finally, future research should accommodate strategic and tactical level alignment in order to develop comprehensive decision analysis.

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APPENDIX B.

PAPER 3.4.4

TIME AND FORM POSTPONEMENT COMPETITION UNDER DYNAMIC BEHAVIOR OF DEMAND

PAPER II

Time and Form Postponement Competition under Dynamic Behavior of Demand

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Abstract
This paper studies assembly-to-order (form postponement) and make-to-stock (time postponement) duopolistic competition under dynamic price and production strategies for two differentiable products, which share common components at a certain degree of substitution. Both strategies are benchmarked according to the Bertrand and Cournot Stackelberg game. In addition, dynamic game is applied to show the long term effect of both strategic decisions (price and production quantity) on profit and against demand uncertainty. The results show that precommited production is appropriate for high modular products and precommited price for special orders. The final part of the paper concludes the results and outlines future research directions.

Keywords: *Strategic Planning, Supply Chain Management, Game Theory, Managerial Flexibility, Market Share, Collaborative Agents*

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1. Introduction

Price and production capacity are two strategic decisions which product managers face over time. Kreps and Scheinkman (1983) showed that if firms choose capacities before engaging in Bertrand-like price competition, then the Cournot outcome is the result if the given capacities are at Cournot levels, or they should be rationed when the capacity cannot meet market demand. Davidson and Doneckere (1986), however, argued against this investigation and showed that the alternative rationing rule can eliminate idle capacity because the players agree to compete at higher equilibrium capacity.

Because the products undertaken by order-based firms are characterized by uniqueness, uncertainty and complexity, however, the Kreps and Scheinkman or Davidson and Doneckere rationing rules are difficult to apply to this type of firm. One reason is that order-based firms are different from mass production-based firms in many respects. These differences extend to their requirements with respect to product proliferation because consumer preferences are diversified among the available brands (Perloff and Salop, 1985). Since a homogenous product gives no options to consumers and diminish brand loyalty (Klemperer, 1992), most discussions of price or production decision focus on their appropriateness, depending on the single firm demand uncertainty (Miegham and Dada, 1999), while the cooperation between make-to-stock and make-to-order based firm is often considered exogenous (Alptekinoglu and Corbett, 2005), so that such models may underestimate the benefit of product substitutability to represent product's customization (Singh and Vives, 1984; Katz and Shapiro, 1985; Perloff and Salop, 1985; Martin S, 1995; Lambertini et al, 2004; Panchal et al, 2007).

With respect to previous efforts in mass customization investigation, so far, few serious attempts have been made to investigate the effect of product substitability degree on make-to-stock and assembly-to-order cooperation by considering the price and production quantity dynamics instead of their values at any given of times. However, the dynamic property is important with regard to the optimum price and quantity decision, at which every player has no reason to change his price or production quantity decision. Our effort in this paper broadly follows Singh and Vives (1984), except that we take into account the possible effects of long term price and production quantity strategic decision, resulting from the presence of order based and stock based firms, and Dr. C.F Ross (1925) in terms of the possible effect of change in the rate of price and production quantity resulting from demand variety. In particular, unlike most of the existing literature on repeated games under product differentiation, we explicitly model those demand uncertainty effects which affect firms' production quantities as well as prices.

In addition to recent literature, the make-to-stock versus make-to-order are represented by two firms is a special case of time and form postponement for a continuous product substitutability distribution. This new approach is quite different to previous methods in the differentiated duopoly game (Singh and Vives, 1984) or price and production postponement (Miegham and Dada, 1999), where the decision is assumed to depend merely on the price or production quantity at any given time, without considering whether the price or production quantity is increasing or decreasing at this time. Even this new approach also quite different to Miegham and Dada (1999), in the light of production and holding costs are assumed under make-to-order or make-to-stock solely, without considering their coexistence under the same product line. Indeed, in order to comprehend price and production contract application to time and form postponement appropriately, we compare Cournot and Bertrand competition in terms of their profitability at several product substitutability degrees and under varied demand.

The following sections first introduce related literature on dynamic analysis in competition, product substitutability in duopoly competition and the research area of this paper (Section 2). Section 3 is started with price (quantity) contract analysis by using the Cournot game model (Section 3.1), which continues with quantity (price) by applying the Bertrand game model (Section 3.2). Section 4 presents and discusses the simulation results, which are concluded in Section 5, which explores the information behind the simulation results in the previous section and discusses some future research opportunities.

2. Related Literatures

Dynamic analysis in competition was firstly presented by Dr. C.F Ross (1925) and it was rediscussed further by Smithies and Savage (1940). Dynamic analysis was used to represent a decision maker who intends to plan his capacity in advance according to the present situation. It is clear that production capacity needs long term planning and the paper addresses a problem of two competitors adapting to a new demand function with the goal of profit stability in the future. In contrast, Dudey (1992) argues against both papers by introducing dynamic Edgeworth-Bertrand competition in order to solve dynamic competition under capacity constraint, which causes Nash equilibrium inexistance. The Dudey model assumes that customers come to the market at different times and the firm's price can be reset at any time with an opportunity that at least one of the duopolists can sell all the units it is able to produce. When this game is a duopoly, the payoff function of each firm maps the duopolists' strategy choices into the firm's total expected profit. Even though the Dudey model used dynamic pricing, this model presents price as a short term decision, which can be changed at any time. However, our model posits price and production quantity as two strategic decisions, which are fixed at a certain finite time in order to handle demand change.

Similar to the approaches of Smithies and Savage (1940) or Dudey (1992) on price and quantity, Singh and Vives (1984) focus their analysis on flexible capacity / price appropriateness to hedge against predetermined price/quantity contracts. Their analysis adapts to a new demand or price after making a price or delivery quantity contract formerly under the absence or presence of product substitutability degree. In contrast to that paper, we contribute to this literature by adding dynamic behavior onto the Singh and Vives (1984) duopoly model by analyzing the impact of demand uncertainty on the firm´s profitability by applying dynamic price or production quantity strategy, which also covers assembly-to-order and make-to-stock firm, which have quantity based total costs instead of marginal cost, according to Cournot or Bertrand. In particular, the Cournot duopoly model (Singh and Vives, 1984) is a special case of price contract and the Bertrand duopoly model a special case of production contract. In conclusion, our contribution is focused on the dynamic analysis of the Singh and Vives model (1984). With a different objective to the Smithies and Savage (1940) or Dudey (1940) models, this paper uses dynamic analysis to investigate the price and production quantity postponement effect on supply chain profit.

3. Introduction to Analytical Model

Suppose now that two firms must agree on two types of contracts: the price contract and quantity contract. Different to Singh and Vives (1984) use predetermined price or quantity to supply customer demand at any levels, our model uses both types of contracts to maximize supply chain profit. To focus discussion, this paper uses Singh and Vives demands and its reverse function by assuming that both products are perfectly substitutes. Effects of this assumption are products have a sticky price and quantity, which enforces both firms to make long term plan for their price and quantity decision. Both firms however are operated under two different manufacturing strategies, namely make-to-stock (time postponement) and assembly-to-order (form postponement). To gather general understanding for dynamic concept for long term price and quantity strategic decision, both time and form postponement will be discussed separately according to static and dynamic games and then general concept will be developed.

3.1 Model Description for Dynamic Cournot Game

In this model we consider a Cournot duopoly model (see Gibbons 1992) with price function for retailers given by

$$P(Q) = a - Q \tag{1}$$

Where Q is total production quantity from both retailers (retailer 1 and 2), a is maximum acceptable market price. In Cournot game firms choose their own quantity to maximize their profit by taking their opponent's quantity as a given, and in Bertrand game they choose their price to maximize their profit by taking their opponent's price as a given. This means that they are going to sacrifice price in Cournot game and quantity in Bertrand game. We propose thus a methodology to avoid this kind of sacrifice by applying Dynamic Stackelberg game just after quantity has been determined.

To illustrate, we suppose two firms must make two types of contracts, namely price and quantity contracts. If the firms choose form postponement, then they must hedge against production fluctuation as a result of demand uncertainty. In this paper, leader firm chooses time postponement and follower firm chooses form postponement. Firms first choose quantity contract and afterwards they compete on the chosen quantities by considering selling and material prices. Restricting attention to the subgame perfect of this two stage game, we shall see that if leader firm chooses time postponement, then predetermined quantity is used to optimize follower firm quantity, where it is finally used by the both firms to optimize their selling price and production quantity. Both firms do not have any benefits by shifting from their optimum point. From this point on, the game is started from stage 2, where both retailers decide their capacity.

In this modeling, we define total costs for both of time postponement and form postponement as

$$E(C_{FP}) = \left(h_2/2\right).q_2 + C_P.q_2/LT + C_W.L + C_m q_2 \tag{2}$$

and

$$E(C_{TP}) = C_O.q_1 + h_1\frac{q_1}{2} + C_{pur}.q_1 \tag{3}$$

Equation (2) and (3) represent the follower firm (Form Postponement) and the leader firm (Time Postponement) costs function. Follower costs function as a function of its production quantity q_2 describes that products assembled by putting material inventory (h_2) and production cost (C_P), which is restricted by limited allowable order queue cost (C_W), delivery lead times LT, and purchased material order (C_m). On the other hand, leader firm cost function as a function of its production quantity q_1 describes leader reserves customers by putting inventory of ready made products in his show-room (h_1), which is ordered from his supplier at cost C_O/item and purchased at C_{Pur}/item. Symmetric information is assumed in this modeling in order to show contract visibility instead of that the products are produced by the same manufacturer.

Stage 2: Quantity contract optimization

In this stage follower firm chooses production quantity to maximize his profit, taking leader firm quantity (q_1) as given. That is, maximize $q_2 = f(q_1)$, derived from profit equation below

$$\underset{q_2}{Max}\,\pi = \left(a - q_1 - q_2 - E(C)\right)q_2 \tag{4}$$

Expected costs E(c) in (4) can be reffered to (2) as equation (4) is a form postponement profit optimization. Furthermore, demand inter-arrival rate and processing rate is assumed according to M/M/1 queue model and total customers in the system can be intrepretated as

$$L = \frac{\rho}{1-\rho} \tag{5}$$

Where ρ is FP service utilization as a function of FP production rate μ and customer demand rates D. That equation informs us about whether there is a delay/backorder or not in our order. Compete equation for form postponement total costs is composed by incorporating (5) into (2) as follow

$$E(C) = \left(C_m + \frac{h_2}{2}\right)\frac{q_2}{2} + C_P.\mu + C_W\frac{\rho}{1-\rho} \tag{6}$$

By combining (4) and (6) and incorporating degree of product substitability (γ) so (4) can be modified according to Cournot duopoly inversion (see Singh and Vives, 1984) as follow

$$\underset{q_2}{Max}\,\pi_2 = \left(\frac{a}{1+\gamma} - \frac{1}{1-\gamma^2}q_1 - \frac{\gamma}{1-\gamma^2}q_2 - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2}\right)\right)(q_2) - \left[C_W\frac{\rho}{1-\rho}\right] \tag{7}$$

Equation (7) can be optimized against q_2 by finding its first order condition. Thus, its production quantity can be founded as

$$q_2 = \frac{\left(1-\gamma^2\right)\left(\frac{a}{1+\gamma} - \frac{q_1}{1-\gamma^2} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2}\right)\right)}{2.\gamma} \tag{8}$$

Equation (8) represents form postponement production quantity by considering leader firm production quantity as given. We see it slope down for the increasing of q_1.

Since two stage games can solve only individual contract, on the contrary, this game uses production quantity and price contracts consecutively. The reason is we assume that the products are perfectly substitutes. We shall use this upcoming section to make price contract for both firms.

Stage 1 Price contract optimization

Singh and Vives (1984) use two stages game, which firm will have to supply the amount the consumers demand at a predetermined price or quantity. This paper applies similar principle as Singh and Vives (1984) except that we take into account both the price and quantity at infinite time in order to optimize supply chain profitability resulting from the presence of long term price and production quantity contract. Different to Stackelberg game of Ferstman and Kamien (1987) and Fujiwara (2006), this stage is developed by finding best price response against production quantity decision, which is resulted from Cournot quantity game. This approach avoids price sacrifice as it is naturally shown by Cournot quantity game and it is shown as follow

$$\dot{p}(t) = s\left(a - q_1 - q_2 - p(t)\right); s > 0; p(0) = p_0 \tag{9}$$

In equation (9) we recognize s as speed of price to go to its optimal value. This speed represents how much time is needed by both firms to negotiate their price contract. This notation finally become insignificant when such a negotiation is done at infinite due date, which both firms are assumed have enough time to analyze their decision. Equation (9) shows how important long term consideration on strategic decision such as price and quantity.

By assuming sticky quantity and prices, then (9) can be reformulated by inserting (8) into (9). Then, a current-value Hamiltonian can be founded as

$$\dot{p}_1(t) = \lambda s\left(\frac{a}{1+\gamma} - \frac{q_1}{2\left(1-\gamma^2\right)} - \frac{\left(\frac{a}{1+\gamma} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2}\right)\right)}{2} - p_1\right) \tag{10}$$

To solve (10), let us set up a current-value Hamiltonian as

$$H = \left(p_1 - \left(C_O + \frac{h_1}{2} + C_{Pur} \right) \right) q_1 + \lambda s \dot{p}_1 \tag{11}$$

S.t (10) $, q_1(t) \geq 0, q_2(t) \geq 0$

Where λ is per unit change of objective function $\left(\max \pi_{(p)}\right)$ for a small change in $p(t)$. At the following derivation we will recognize δ as a compound factor, which represents how much penalty cost must be given each time both firms repeat their contract negotiation. This assumption is used to force both firms to achieve a contract aggrement as soon as possible. However, this notation finally become insignificant when such a negotiation is done at infinite due date, which both firms are assumed have enough time to analyze their decision. We can prove this insignificancy at the following derivation.

$$\frac{\partial H}{\partial q_1} = \left(p_1 - \left(C_O + \frac{h_1}{2} + C_{Pur} \right) \right) - \frac{\lambda . s}{2\left(1 - \gamma^2\right)} = 0 \tag{12}$$

$$\dot{\lambda}_1 = \delta . \lambda_1 - \frac{\partial H}{\partial p} = \lambda_1 (\delta . + .s) - q_1 = 0 \tag{13}$$

Steady state price can be found from (12) and (13) by setting time as infinite ($s \to \infty$)

$$\lim_{s \to \infty} p_1 = \left(C_O + \frac{h_1}{2} + C_{Pur} \right) + \frac{q_1}{2\left(1 - \gamma^2\right)} \tag{14}$$

By inserting (8) into Cournot duopoly inversion, then p_1 can be reformulated as

$$p_1 = \frac{a}{1+\gamma} - \frac{q_1}{2\left(1 - \gamma^2\right)} - \frac{\left(\frac{a}{1+\gamma} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2} \right) \right)}{2} \tag{15}$$

Solve (14) and (15) simultaneously and finally leader optimum price and quantity can be stated as

$$q_1 = \left(1 - \gamma^2\right) \left(\frac{a}{1+\gamma} - \frac{\left(\frac{a}{1+\gamma} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2} \right) \right)}{2} - \left(C_O + \frac{h_1}{2} + C_{Pur} \right) \right) \tag{16}$$

With the same way, p_2 could be obtained as

$$p_2 = \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2} \right) \tag{17}$$

3.2 Model Description for Dynamic Betrand Game

In this model we consider a Cournot duopoly model (see Gibbons 1992) with price function for retailers given by

$$Q = b - p_i + \gamma . p_j \tag{18}$$

Where Q is total production quantity from both retailers (retailer 1 and 2), b is total market size, and p_i and p_j is price of product 1 and 2.

In the Bertrand game both firms choose their own price to maximize their profit simultaneously by taking product substitutability degree as a given. We thus propose a methodology which is similar to the previous Cournot game, except that we take into account the quantity at infinite time in order to optimize the postponed decision resulting from the presence of long term quantity contract.

Since two-stage games can solve only an individual contract, this game uses product price and quantity contracts consecutively. The reason is we assume that the products are perfect substitutes.

Stage 2 Follower decide his price according to leader price

$$\max_{p2} (b - p_2 + \gamma . p_1) \left(p_2 - \left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m \right) q_2 - C_W . L \right) \tag{19}$$

Solving that equation for p_2 and by finding relationship of $b + \gamma . p_1 = q_2 + p_2$, one can obtain

$$p_2 = \frac{\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1 \right) . (b + \gamma . p_1) + C_W . L}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m \right)} \tag{20}$$

Stage 2 explores price equilibrium between two buyers. This equation shows effort to maximize standard platform utilization by increasing product substitutability value. Furthermore both prices are used to decide production quantity as follow

Stage 1 Capacity postponement decision

Singh and Vives (1984) use two stages game, which firm will have to supply the amount the consumers demand at a predetermined price or quantity. This paper applies similar principle as Singh and Vives (1984) except that we take into account both the price and quantity at infinite time in order to optimize supply chain profitability resulting from the presence of long term price and production quantity contract. Different to Stackelberg game of Ferstman and Kamien (1987) and Fujiwara (2006), this stage is developed by finding best price response against price decision, which is resulted from Bertrand pricing game and it is shown as follow

$$\dot{q}(t) = s(q - q(t));\, s > 0;\, q(0) = q_0 \tag{21}$$

In equation (21) we recognize s as speed of quantity to go to its optimal value. This speed represents how much time is needed by both firms to negotiate their quantity contract. This notation finally become insignificant when such a negotiation is done at infinite due date, which both firms are assumed have enough time to analyze their decision. Equation (21) shows how important long term consideration on strategic decision such as price and quantity.

To solve (21), let us set up a current-value Hamiltonian as

$$H_1 = q_1.p_1 + \lambda_1 s(a - p_1 + \gamma.p_2 - q_1) \tag{22}$$

S.t (21), $q(t) \geq 0$,

Where λ is per unit change of objective function $\left(\max \pi_{(q)}\right)$ for a small change in $q(t)$. At the following derivation we will recognize δ as a compound factor, which represents how much penalty cost must be given each time both firms repeat their contract negotiation. Similar to Dynamic Cournot game, leader optimum price and quantity can be stated

$$p_2 = \frac{b + \gamma.p_1 + \left(\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m\right).q_2 + C_W.L\right)}{2} \tag{23}$$

$$q_2 = b - \frac{\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1\right).(b + \gamma.p_1) + C_W.L}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m\right)} + \gamma.p_1 \tag{24}$$

We can see that equilibrium quantity and price is a concave function of product substitability (γ). In conclusion, this parameter gives positive impact to supplier-buyer join product development since the increasing of substitutability degree also increases supply chain profitability.

Below, Static Cournot and Bertrand game are given to illustrate the advantage of dynamic Cournot and Bertrand Stackelberg games as follow.

3.3 Static Cournot and Bertrand Game

3.3.1 Static Cournot Game

In this section, a static Cournot Stackelberg game is derived in order to compare with the above dynamic Cournot Stackelberg game. Let us start it by utilizing equation (8) into (3) as follow

$$\underset{q_1}{Max}\,\pi_1 = \left(a - \frac{\gamma(1-\gamma^2)\left(\frac{a}{1+\gamma} - \frac{q_1}{1-\gamma^2} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2}\right)\right)}{2.\gamma(1-\gamma^2)} - \frac{q_1}{(1-\gamma^2)} - \left[C_O + C_{Pur} + \frac{h_1}{2}\right] \right)(q_1) \tag{25}$$

By optimizing (25) then we find q_1 as

$$q_1 = (1-\gamma^2)\left(a - \frac{\gamma(1-\gamma^2)\left(\frac{a}{1+\gamma} - \left(\frac{C_P}{LT_2} + C_m + \frac{h_2}{2}\right)\right)}{2.\gamma(1-\gamma^2)} - \left[C_O + C_{Pur} + \frac{h_1}{2}\right] \right) \tag{26}$$

Insert (8) and (26) into Cournot duopoly inversion (see Singh and Vives, 1986) the p_1 and p_2 are simply calculated according to

$$P_1 = \frac{a}{1+\gamma} - \frac{1}{1-\gamma^2}q_1 - \frac{\gamma}{1-\gamma^2}q_2 \tag{27}$$

$$P_2 = \frac{a}{1+\gamma} - \frac{\gamma}{1-\gamma^2}q_1 - \frac{1}{1-\gamma^2}q_2 \tag{28}$$

3.3.2 Static Bertrand Game

In this section, a static Cournot Stackelberg game is derived in order to compare with the above dynamic Stackelberg game. Let us start it by utilizing equation (8) into (4) as follow

$$\underset{p_1}{Max}\,\pi_1 = \left(b + \gamma \frac{\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1\right).b + C_W.L}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m\right)} + \left(\frac{\gamma^2\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1\right)}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m\right)} - 1 \right) p_1 - \left[C_O + C_{Pur} + \frac{h_1}{2} \right] \right) (p_1) \tag{29}$$

By optimizing (29) for p_1, one obtains

$$p_1 = \frac{\left(b + \gamma \frac{\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1\right).b + C_W.L}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m\right)} - \left[C_O + C_{Pur} + \frac{h_1}{2} \right] \right)}{\left(2 - \frac{2\gamma^2\left(\frac{h_2}{2} + \frac{C_P}{LT} + C_m + 1\right)}{\left(2 + \frac{h_2}{2} + \frac{C_P}{LT} + C_m\right)} \right)} \tag{30}$$

Insert (30) into (20) and use both of them into (8), then, q_1 and q_2 are simply calculated according to

$$q_1 = b - p_1 + \gamma.p_2 \tag{31}$$

$$q_2 = b - p_2 + \gamma.p_1 \tag{32}$$

4. Discussion

Studies on time and form postponement have been able to shed light on the supply chain as a dynamic system. In addition, they have underscored the importance of such long term stability as values, meanings and commitments and paved the way for more elaborate research on interface between supply chain and revenue management.

What happens if both firms incorporate the long term pricing decision while applying time and form postponement at different game strategies? In that case both firms choose price to maximize their profit, taking q as given. This yields the profit reaction which corresponds to the Cournot reaction. Notice that it is downward sloping for the increasing of product substitutability degree (see figure 1).

The similar action is shown for static Cournot Stackelberg game, where firms choose price to maximize profit. We can see from these two kinds of games that dynamic game has higher profit level than static ones. That discrepancy informs us that long term decision must consider about dynamic property of the contract. Furthermore, dynamic game gives more opportunities to be applied at higher substitutability degree gives more opportunity to (see Figure 2).

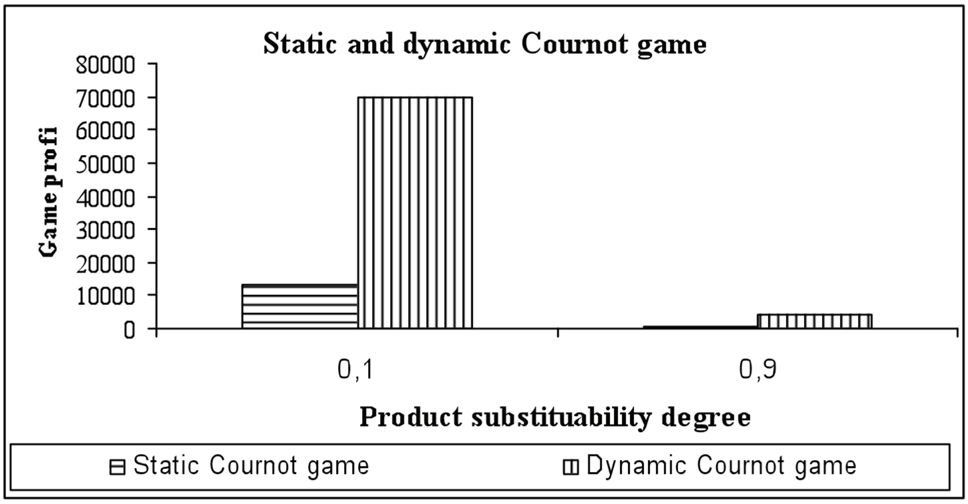

Figure 1 Static and dynamic Bertrand game profit comparison

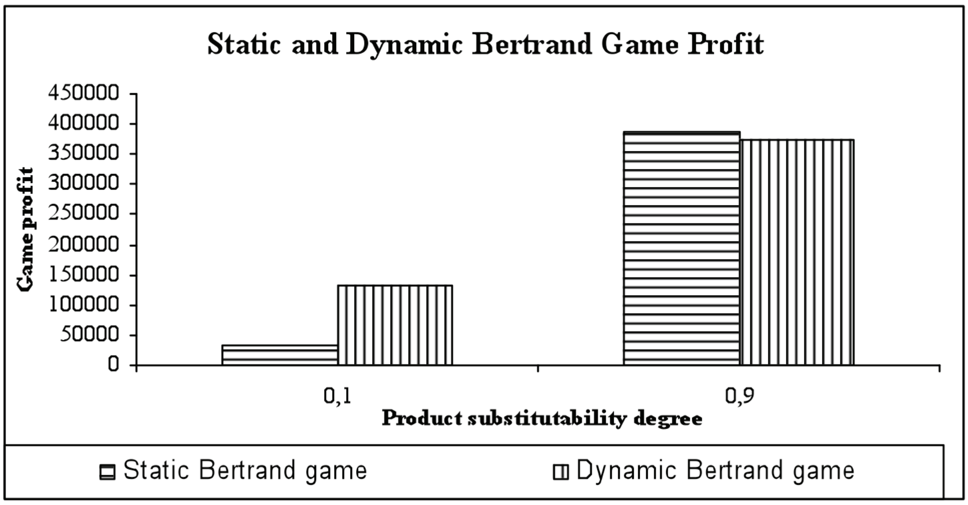

Figure 2 Static and dynamic Cournot game profit comparison

To examine the case with erratic demands, suppose firms strictly predetermine their price and quantity settings, which is strictly revised in their profitability. Now if we randomize a or b value to represent demand variety, then we get $\pi_{(p)}$ or $\pi_{(q)}$ as a function of q , p and γ ; hence, the results can be drawn as follows

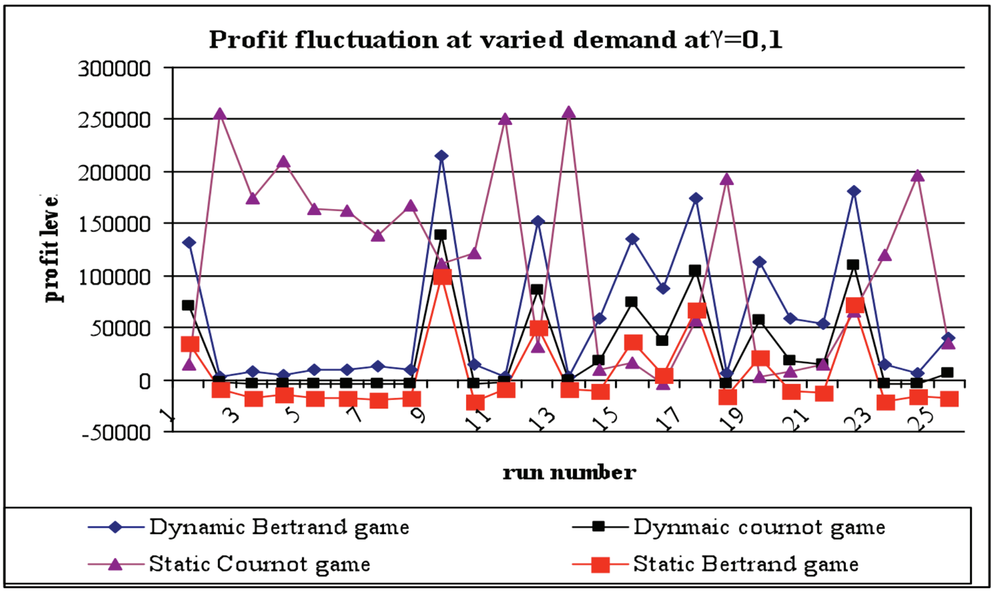

Figure 3 Static and dynamic Cournot and Bertrand game profit at varied demand at low product substitutability (γ=0,1)

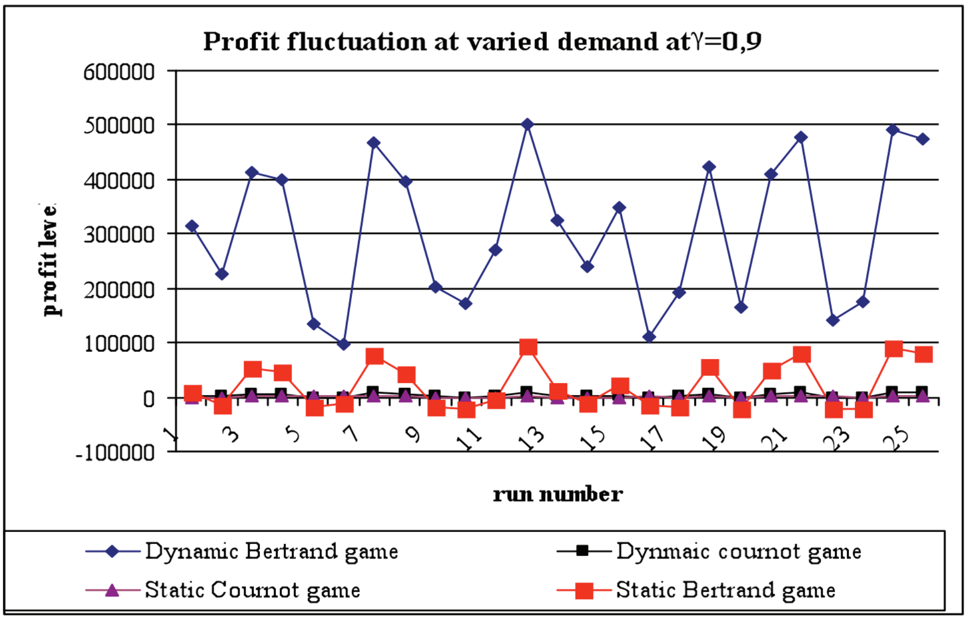

Figure 4 Static and dynamic Cournot and Bertrand game profit at varied demand at high product substitutability (γ=0,9)

Figure 3 and 4 clearly show that dynamic production contract game (Cournot game) is more favourable at high substitutable products at varied demands, which is shown by least fluctuations than price contract (Bertrand game) at high product substitutability degree (please compare its fluctuation according to γ=0,1 and γ=0,9). These results again ensure that long term decision on how many to produce is appropriate at higher compatible products instead of how much the price at less compatible product.

We know that profit stability is a common goal of price and production quantity contracts. High profit stability ensures two firms can cooperate without worrying about any losses. Below is a comparison between two games types, which is gathered by finding profit at different price or quantity settings. Now if we measure their deviation from optimum profit value (replace q or p by our own assumption), then we get $\pi_{(p)}$ or $\pi_{(q)}$ as a function of q, p and γ. Benchmarking them against optimal value, the results are

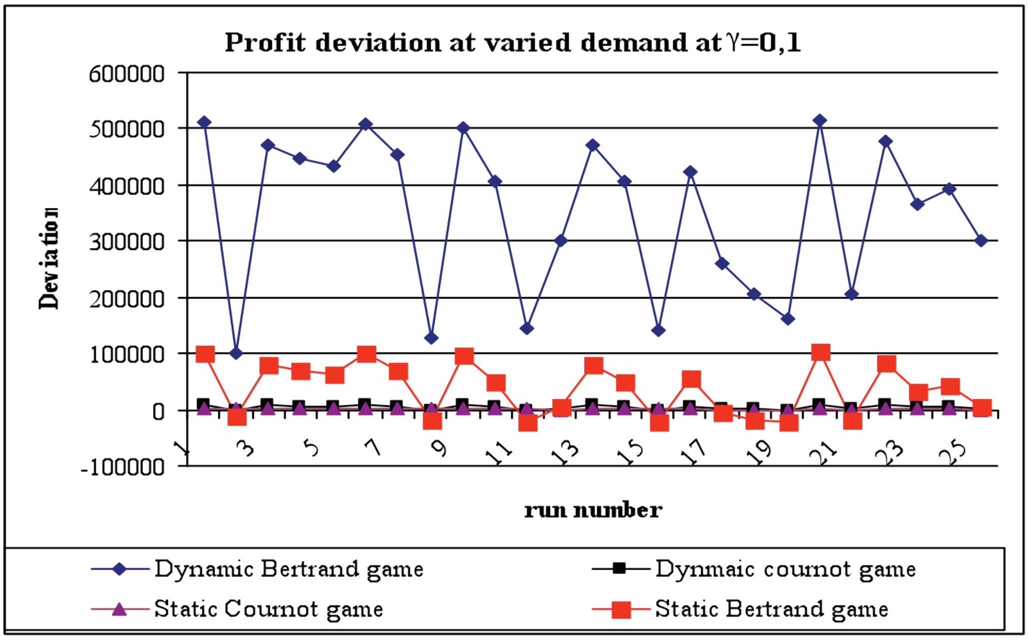

Figure 5 Static and dynamic Cournot and Bertrand game profit dynamics at varied demand at low product substitutability (γ=0,1)

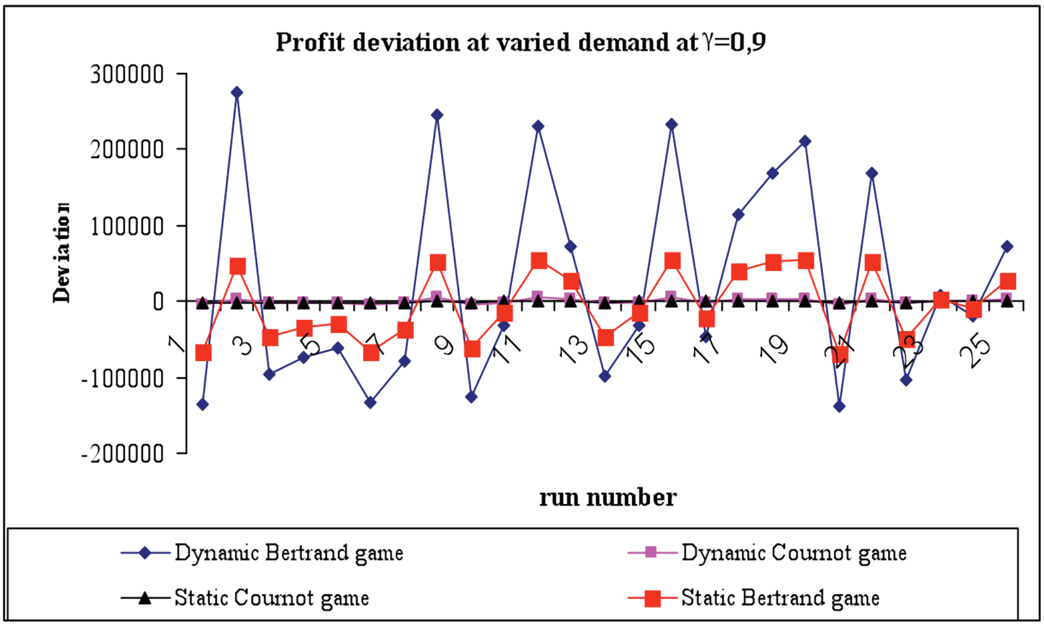

Figure 6 Static and dynamic Cournot and Bertrand game profit dynamics at varied demand at high product substitutability (γ=0,9)

Figure 5 and 6 clearly show that dynamic production contract game (Cournot game) is more favourable at at varied demands, which is shown by less deviation than price contract (Bertrand game) at high product substitutability degree (please compare its fluctuation according to γ=0,1 and γ=0,9). These results again ensure that long term decision on how many to produce is appropriate at higher demand variety.

In addition to the managerial implication, dynamic stackelberg game is also significantly superior to static Cournot game from the customer service level point of view (see Figure 5). That figure shows that the proposed game can cover market demand at a higher level than static Cournot game. This result supports the managerial policy of product commonality, where price can be determined later after final customization is completed.

Furthermore, dynamic Stackelberg game is still superior over static Cournot game at a higher product substitutability degree. This result once more supports the view that static Cournot game is only appropriate to highly unique products. The reverse result is shown for dynamic Stackelberg game, where firms develop a common platform to maximize profit.

5. Conclusion and Further Research

This paper revisited the Singh and Vives model on price and production predetermined contract by considering the dynamic behavior of demands onto make-to-stock and assembly-to-order competition. We may summarize the results derived from the model, as follows.

Production contract is superior to price contract at many respects. This type of contract guarantees profit stability and at the same time supports the product standardization effort

Production quantity contract is also a dominant strategy for substitutable products. This conclusion is at odds with the previous Singh and Vives conclusion (Singh and Vives, 1984). This discrepancy is caused by the Singh and Vives model perhaps assuming that in Bertrand price-like competition, the quantity setting will avoid both firms having to reduce their production quantity further. On the contrary, this paper assumes sticky prices and quantities, where it pushes both firms to cooperate at higher levels. By sticky prices and quantities, this paper is more appropriate for common platform based products instead of two widely differentiated products.

Price contract is a dominant strategy for highly differentiable products of make-to-stock and assembly-to-order competition. This conclusion supports the article of Miegham and Dada (1999), who discusses postponement strategies differentiation according to their applicability.

The dynamic behavior analysis in this paper helps decision makers to decide their long term price and production quantity policy with regard to their manufacturing types, namely make-to-stock and assembly-to-order. The analysis results also support both modularity and customization principles in mass customized products, where decision uncertainty can be reduced by making closer customer order decoupling, point of sales. This paper suggests product developers to design common platform products and decide the price according to customer specific requirements.

In terms of future research direction, the oligopoly model should be considered for development according to future market demand, which is determined by how close customer requirements are met, so in future the oligopoly model quantity and price can be replaced with some parameters such as inventory and lead times. From this result, a sequence between lead times and inventory can be determined and the outcome will be a decision about whether agility or efficiency is more important for a company, so that the outcome can be used by top management to compose their business strategy. Finally, future research should accommodate strategic and tactical level alignment in order to develop comprehensive decision analysis.

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APPENDIX C.

PAPER 3.4.5

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Strategic thinking in supply and innovation in dual sourcing procurement

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Abstract: This paper focuses on decision making related to the use of strategic thinking in dual sourcing. The general purpose is to present a novel approach to managing strategic moves by considering the suppliers' possible actions in terms of supply uncertainty and product substitutability by considering the buyer and the suppliers' payoffs. Strategic competitiveness is optimised by finding the optimum selling price for the buyer and suppliers as well as the innovation level through product substitutability. The results show that innovation makes procurement costs higher in dual sourcing. With respect to managerial implication, this paper suggests that the buyer should encourage innovation by offering higher incentives to the suppliers as well as imposing penalties for lack of promptness in supply. It is also suggested that strategic thinking is appropriate for mass customised and highly innovative products.

Keywords: strategic thinking; innovation; game theory; competitiveness; dual sourcing procurement.

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1 Introduction

The need for a wider array of sourcing frameworks by presenting competitive advantage has replaced the current trend in strategic sourcing decision-making from cost reduction to the ability of core competence identification (Venkatesan, 1992; Sislian and Satir, 2000). With regard to the issue of competitiveness, Venkatesan (1992) introduced 'core competence' as a significant source of differentiation, a unique signature of the organisation and future advantage consideration. Prahalad (1993) insisted on core competence as a collective action of technology, governance process and collective learning. If the manufacturer does not have the capability (resources and time) to invest in strategic activities, then strategic sourcing is the option. Strategic sourcing is intended only as a strategic item or activity which has high impact on and risk for the buyer (Kraljic, 1983).

Strategic sourcing is advantageous when we study mass customised products, where innovation is strongly needed to hedge against customer requirement varieties and competitors' efforts to mimic the product (Jennings, 2002). Dual sourcing is needed to ensure supply flexibility in multi-product problems (Tomlin and Wang, 2005). Examples of dual sourcing applications are Japanese vehicle manufacturing companies such as Honda, with 44% of its parts having two suppliers and Toyota, which outsourced 38% of its parts to two suppliers (McMillan, 1990). In addition to dual sourcing, Tomlin and Wang (2005) apply dual sourcing and mix a combination of flexibility with lower procurement cost. However, thus far few serious attempts have been made to study the causal effect of dual sourcing and mixing flexibility with increased profit (Kim, 2000) instead of reducing lead times and inventory level uncertainty at the tactical level (Fong et al., 2000; Ryu and Lee, 2003).In a similar way to the flexibility point of view, strategic thinking in dual sourcing is also important in terms of communication and innovation (Goffin et al., 1997). However, by analysing a case study of four electronics plants, Goffin et al. (1997) found that none of them deemed dual sourcing an equal opportunity for both suppliers to supply manufacturers' orders instead of splitting them into main and backup suppliers. Anton and Yao (1992) used auction theory to argue that when innovation is a key competitive dimension, this increases the attractiveness of a split award auction format to the buyer. Moreover, communication can be improved by revealing the suppliers' cost to the buyer to produce a reasonable price through the application of bidding competition. In application, Japanese companies regularly audit their suppliers' performance in terms of process capability and accountability (McMillan, 1990). A suppliers' audit enables the buyer to examine the suppliers' costs so that the buyer can offer an optimum price to the suppliers.

In addition to the application of dual sourcing, it is used more often in circumstances where bidding collusion is less or the supplier has experience of a quality control problem (Lyon, 2006). There is no evidence that dual sourcing is used in response to procurement profit improvement by presenting innovation as a key competitive dimension. As a result, this research does not attempt to persuade the reader to regard flexibility as a requirement for dual sourcing, nor to ascertain whether it is cooperative or non-cooperative suppliers that are the focus of dual sourcing. Indeed, by considering the three strands of competition in procurement (Lyon, 2006), this paper gives insight by firstly addressing the claim that dual sourcing supports innovation (Anton and Yao, 1992), since this is the most prominent literature in dual sourcing and secondly, it addresses the issue of the connection between dual sourcing procurement cost and innovation performance at the research and development (R&D) phase of procurement (Lyon, 2006).

In summary, this section presents several research questions by addressing some future research directions from the literature. The research questions are not mutually exclusive and all of them are solved by developing analytical models. The models are derived by combining innovation and economic behaviour in dual sourcing when its insights seem robust for the use of true dual sourcing by considering the rationality of the buyer and suppliers. The research questions are as follows:

- Research question 1: Lyon (2006) concludes that dual sourcing lowers procurement costs where it is focused on the price benefits of competition and does not attempt to measure the suppliers' innovation investment. This recent paper also investigates the possibility of dual sourcing to lower procurement cost by focusing on the price benefits of competition where suppliers' innovation at the R&D phase of procurement is considered. Thus, the first research question can be formulated as: 'What is the connection between dual sourcing procurement cost and innovation performance at the R&D phase of procurement?'.
- Research question 2: Related to the first research question, achieving price benefits from the competition between two suppliers and encouraging suppliers' innovation are two contradictory objectives. The higher the suppliers' innovation level, so the higher is the procurement price required by the buyer from the suppliers. Thus, the buyer needs to formulate a strategy whereby the benefit from the suppliers' innovation must be higher than the price benefits from the competition of two suppliers. From these requirements, the second research question can be formulated as: 'How can a strategy be formulated to maximise the buyer and suppliers' payoff by innovation when dual sourcing cannot lower the procurement cost?'.

One important issue in strategy formulation is that the strategy must not give an opportunity to the buyer or the suppliers to achieve their optimum pay-offs regardless of their partners' possible reactions. Thus, strategic thinking-based analytical models are developed by considering that the chosen strategy should be credible from the buyer and the suppliers' point of view. Credibility can be used by the buyer to stop the suppliers doing something they would otherwise do ('deterrence') or induce them to do something they would not do otherwise ('compulsion').

In terms of research methodology, analytical models are chosen as compared to other methodology, for instance discrete event simulation and case study. The reasons can be summarised as follows.

First, the objective of this research is how to formulate competitive strategy for the buyer and the suppliers when product innovation is considered. Thus, the buyer and the suppliers' strategy domains are situated in terms of choosing whether to be cooperative or not by making innovation. Cooperative action is shown by reducing supply and demand uncertainty for the partners. From this point on, the buyer and the suppliers' strategic moves are clearly identified so that the exact analytical model can represent the relationship closely.

Second, it is possible to use this research to test and modify new theory on strategy formulation in dual sourcing procurement by the existence of product innovation. Previously, many researchers believed that dual sourcing can lower procurement cost (Lyon, 2006) and it can be done effectively if the two suppliers are innovative in a cost reduction program (Anton and Yao, 1992). No previous research offers preventive strategy by applying strategic moves instead of curative strategy by analysing non-root cause factors, for example controlling lead times by applying stochastic inventory model (Fong et al., 2000; Ryu and Lee, 2003). From this situation, strategy formulation in dual sourcing procurement needs to be focused on stopping the suppliers from doing something they would otherwise do ('deterrence') or inducing them to do something they would not do otherwise ('compulsion').

The validity of the analytical model can be improved by using empirical information to estimate analytical model parameter value. An example of this application is dual sourcing in the US Department of Defence procurement in using a simultaneous equation model and combining it with empirical information to estimate the parameter values, for instance learning curve and average cost curve unique to each problem or case (Lyon, 2006). Another example is Novak and Eppinger (2001), who focused on the connection between product complexity and vertical integration using original empirical evidence from the automobile industry. A statistical model was developed to represent product complexity and vertical integration by interviewing project managers, system engineers, design engineers, purchasing managers and manufacturing engineers for each vehicle for each time period in the study. Abrate (2008) developed an econometric model to estimate the elasticities of substitution across time using a sample of Italian industrial customers facing a time of use pricing scheme. The above examples give some evidence that analytical models can also be aligned with empirical information.

Without undermining the importance of empirical information for our analytical model, this current research excludes the application of empirical information by considering that the objective is to show to the readers how to formulate strategy for dual sourcing procurement where product innovation is considered. Thus, the outcome of this current research is giving guidance on how to move strategically against partners' strategy for dual sourcing procurement.

Certainly, different company situations will give different outcomes if empirical information is included, but the principle is the same, that is to alter the actions of other players later in the procurement process by manipulating the rules of a procurement contract by putting emphasis on credibility.

Without ignoring other research methods, this research excludes the application of discrete event simulation, where it is possible to introduce a random number generator to represent operational performance. Though the case study has the potential to be applied in strategy research by identifying similarities and differences across firms that give various responses or strategic moves, it still cannot replace the main role of analytical model application, because the case study perspective is to find out different responses across firms on strategic moves without changing the rules of strategic moves. In that case, the case study can potentially be applied to measure the buyer and the suppliers' performance at different responses. One example of this opportunity comes from the development of a supply chain performance measurement system (PMS) of the European operations of Nike (Lohman et al., 2004). A score card has been developed for measuring the performance of customers, sustainability, finance, process improvement, product flow and people. Since the case study is intended to understand the effect of a parallel score card within supply chains, it can be used to identify the similarities and differences of firms' responses or strategic moves.

The following sections first introduce related literature on dual sourcing competition and also the research area of this paper (literature review section). The introduction to the analytical approach section is started by pricing decision analysis using the Bertrand game model, which continues with the buyer and suppliers' strategic moves. The problem example and data analysis section presents and discusses the problem example and its results, which are concluded in the sections on managerial implications, conclusions and further research, which explore the information behind the simulation results and discuss some future research possibilities.

2 Literature review

The concept of tailored sourcing in the supply chain has been presented by Chopra and Meindl (2004), who discuss tailored sourcing in order to reduce supply uncertainty. Furthermore, Tulluous and Uttech (1992) state that multi-sourcing is more appropriate to low need uncertainty than high market and transaction uncertainty. Conversely, we use supply uncertainty and need uncertainty to investigate possible strategic moves application by the buyer to attract the suppliers' collaboration, as well as to investigate the suppliers' competition (Forker and Stannack, 2000).

Patterson et al. (1999) focus on a longer-term supplier-buyer relationship based on goal congruency, so that cooperation level is the key issue. Furthermore, their paper proposes a transcendental relationship model besides a transitional and transactional one by adding outcome maximisation and a high level of interdependence between supplier and buyer.

A supplier-buyer relationships model, however, is argued by Forker and Stannack (2000), who describe supplier competition in terms of an arms-length relationship as useful to maintain optimal performance from the supply side. Furthermore, the authors state that it is appropriate to apply bureaucracy to unique resources with predictable and frequent transaction (Patterson et al., 1999) instead of supplier-buyer relationships. Two surveys from the electronic and aerospace industries show that a relationship according to competition is preferred to cooperation in a buyer-supplier relationship (Forker and Stannack, 2000). Forker and Stannack concluded that the more strategic the supplier is from the buyer point of view, the more cooperation is preferred to competition. This paper, conversely, proposes competition in strategic suppliers by applying dual sourcing to attract competition between two suppliers.

Supplier-buyer competition expansion from single to multi-sourcing is also discussed in Elmaghraby (2000), based on the work of Horowitz (1986), in buying decisions according to price uncertainty. Burke et al. (2007) insist on multi-sourcing when single supplier capacity is not sufficient to meet customer demand, regardless of product innovation to produce flexibility. On the other hand, Kim (2000) proposes incentives to the single supplier to induce innovation by stating that the incentive will be effective when the supplier profit increases. Wagner and Friedl (2007), however, propose the application of dual sourcing, by arguing that it is better to switch partially to another supplier whenever the buyer observes that the incumbent supplier's cost is higher than the entrance supplier, in order to induce competition in terms of purchasing cost. On the other hand, Anton and Yao (1989) conclude that dual sourcing is not favoured when both suppliers collude to reduce the innovation effort, so that the two suppliers act as monopolists. The effect of this action is that the suppliers' product will be highly differentiated and the sourcing price becomes lower because of the expansion of the total market size.

In addition to it being a dual sourcing requirement, Anton and Yao (1989) regard innovation as a way of inducing competition between two suppliers. The implication of this is that the information exchange between the two suppliers should be symmetrical in terms of selling price and product design. Supporting Anton and Yao's (1989) proposal, we contribute to the literature by adding innovation to the supplier's competition in dual sourcing by analysing the impact of innovation on the buyer strategic moves, which is determined by optimising the buyer and the suppliers' payoffs. In particular, threats and promises are used to represent the buyer's strategic moves towards the suppliers in minimising supply uncertainty. In conclusion, our contribution is focused on infusing strategic thinking into dual sourcing in order to investigate the causal effect of strategic moves on suppliers' innovation decisions.

3 Introduction to analytical model

Suppose now that two suppliers can agree on only two types of flexible contracts from the buyer: price and quantity contract. From this point on, we refer our discussion on price and quantity contract to support sourcing strategy by applying a strategic moves game. From the buyer side, a conditional strategic moves game brings an actual gain, if the buyer chooses a response rule, than in some eventualities where an action is specified different from the optimal strategy. Thus, the credibility of the buyer's strategy is unquestionable because the suppliers also have possibilities to receive a promise or be threatened. On the other hand, from the supplier's side, as a first mover, the suppliers can take advantage by proposing product price and innovation level by changing the product substitutability degree γ.

Figure 1 Strategic form of game between buyer and suppliers

		First Mover	
		The Suppliers' strategy	
		Cooperate $\sigma_s = 0$	Not Cooperate $\sigma_s \geq \frac{\varepsilon_s}{Z}$
Second Mover The Buyer's strategy	Cooperate $\sigma = 0$	π_{s1} Strategy I π_{b1}	π_{s2} Strategy II π_{b2}
	Not cooperate $\sigma \geq \frac{\varepsilon_b}{Z}$	π_{s3} Strategy III π_{b3}	π_{s4} Strategy IV π_{b4}

To induce the suppliers to be more innovative, the buyer can derive benefit from collaboration by imposing on the suppliers penalty cost p if the suppliers cannot meet the demand requirement q at total market demand b with standard deviation σ by supplying lower quantity – $q_s\big|_{(b-\varepsilon)^+}$, or higher quantity – $q_s\big|_{(\varepsilon-b)^+}$. By taking confidence level α = 95%, where the buyer wants the probability of stock out Prob($q > q_s$) to be no more than 5% and the market demand is normally distributed, then the market demand standard deviation σ at $\varepsilon_b \geq 1$ can be found as $\sigma \geq \frac{\varepsilon_b}{Z}$, where Z is used to designate standard normal variable. $\sigma \geq \frac{\varepsilon_b}{Z}$ represents the non-cooperative action of the buyer by giving demand information to the supplier more or less than the actual market demand. Similarly, the supplier can also threaten the buyer by becoming non-cooperative at $\sigma_s \geq \frac{\varepsilon_s}{Z}$ by taking $\varepsilon_s \geq 1$. Conversely, the supplier will receive incentive I when the supplier can make $\sigma = 0$ or the suppliers can supply at $q_s = q$.

Beforehand, a competitive strategy in terms of suppliers' product price p^* and supply quantity q^* needs to be optimised for the contract between the buyer and the suppliers by considering the strategic moves of the buyer in order to obtain higher payoffs.

The following discussion is focused on the development of the strategic moves game by offering penalty cost p and incentive I to support the strategic moves game of the buyer as a second mover. Thus, we have the following strategic form of the game.

Figure 1 presents the game between the buyer and the suppliers, where both have two strategic options. The buyer can play either a cooperative or non-cooperative strategy by introducing conditional strategic moves. Similarly, the suppliers can also play either a cooperative or non-cooperative strategy by moving strategically according to the conditional strategic moves. Beforehand, all of the strategy couples will be optimised in order to investigate the most optimum strategy.

3.1 Buyer strategy (second mover)

Suppose in the delivery contract the buyer as a customer takes the initiative by announcing a contract proposal which contains some requirements, for instance prices and the buyer and the suppliers' responsibilities. Thus, the buyer acts as a second mover. Beforehand, the buyer needs to optimise the buyer selling price according to the suppliers' auction price p_s as follows.

$$\max_{p_b}\left(\varepsilon_b-(1-\gamma)\,p_b\right)\left(p_b-p_s\right) \tag{1}$$

By optimising (1) against p_b, then the buyer selling price p_b can be found as

$$p_b=\frac{\varepsilon_b+(1-\gamma)\,p_s}{2.(1-\gamma)} \tag{2}$$

To simplify the calculation, $b + \varepsilon_b$ can be replaced by ε. $\gamma = 0$ implies that each supplier is a monopolist in the supplier's respective market and the product becomes fully flexible when γ approaches unity. The suppliers' selling price p_s in (2) can be categorised as the price at over-estimation $p_{f\left(\varepsilon_b\geq 1(\varepsilon-b)^+\right)}$, at under-estimation $p_{f\left(\varepsilon_b\geq 1(b-\varepsilon)^+\right)}$ and at the buyer's demand $p_{f(\varepsilon=b)}$. Similarly, the buyer selling price p_b is also categorised as the price at over-estimation $p_{b\left(\varepsilon_b\geq 1(\varepsilon-b)^+\right)}$, at under-estimation $p_{b\left(\varepsilon_b\geq 1(b-\varepsilon)^+\right)}$ and at the buyer's demand $p_{b(\varepsilon=b)}$.

Suppose the buyer has to decide on penalty cost p and incentive I for the suppliers whenever they can meet the demand in the market $\sigma_s = 0$. If the forecasting accuracy

(ε_s = 0) is to be a common objective between the suppliers, then for each supplier, penalty p and incentive I costs must at least equal to the total cost changes due to the demand and supply uncertainty and by considering that the supplier will receive at penalty if and only if $\sigma_s \geq \frac{\varepsilon_s}{Z}$.

If the same situation can be applied to the incentive to the suppliers, then I and p are equal to

$$p/I = \begin{cases} \varepsilon_s \geq 1, p = \alpha.c_{(b-\varepsilon)^+}.q_s\big|_{(b-\varepsilon)^+} + (1-\alpha).c_{(\varepsilon-b)^+}q_s\big|_{(\varepsilon-b)^+} \\ \varepsilon_s = 0, I = c_{\varepsilon_s=0}.q \end{cases} \tag{3}$$

Where $c_{(\varepsilon-b)}$ and $c_{(b-\varepsilon)}$ are the suppliers' total costs in the buyer's non-cooperative strategy of over and under market demand estimation, respectively. Further, the suppliers' total costs with the buyer's cooperative strategy can be designated as $c_{(\varepsilon=b)}$. The value of the suppliers' total cost will be optimised at Stage 1 of the suppliers' strategy.

Then the buyer profit function can be determined as

$$\pi_{b1}(\sigma = 0; \sigma_s = 0) = q_s\big|_{(b=\varepsilon)} \cdot \left(p_{b(\varepsilon=b)} - p_{f(\varepsilon=b)}\right) \tag{4}$$

$$\begin{aligned} \pi_{b2}\left(\varepsilon_b = 0; \sigma_s \geq \frac{\varepsilon_s}{Z}\right) &= (1-\alpha)q_s\big|_{(\varepsilon-b)^+} \cdot \left(p_{b(\varepsilon=b)} - p_{f\left(\varepsilon_b \geq 1(\varepsilon-b)^+\right)}\right) \\ &+ \alpha.q_s\big|_{(b-\varepsilon)^+} \cdot \left(p_{b(\varepsilon=b)} - p_{f\left(\varepsilon_b \geq 1(b-\varepsilon)^+\right)}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} \pi_{b3}\left(\sigma_b \geq \frac{\varepsilon_b}{Z}; \sigma_s = 0\right) &= (1-\alpha)(q_s = q).\left(p_{b\left(\varepsilon_b \geq 1(\varepsilon-b)^+\right)} - p_{f(\varepsilon=b)}\right) \\ &+ \alpha.(q_s = q).\left(p_{b\left(\varepsilon_b \geq 1(b-\varepsilon)^+\right)} - p_{f(\varepsilon=b)}\right) \end{aligned} \tag{6}$$

$$\begin{aligned} \pi_{b4}\left(\sigma_b \geq \frac{\varepsilon_b}{Z}; \sigma_s \geq \frac{\varepsilon_s}{Z}\right) &= (1-\alpha).q_s\big|_{(\varepsilon-b)^+} \cdot \left(p_{b\left(\varepsilon_b \geq 1(\varepsilon-b)^+\right)} - p_{f\left(\varepsilon_b \geq 1(\varepsilon-b)^+\right)}\right) \\ &+ \alpha.q_s\big|_{(b-\varepsilon)^+} \cdot \left(p_{b\left(\varepsilon_b \geq 1(b-\varepsilon)^+\right)} - p_{f\left(\varepsilon_b \geq 1(b-\varepsilon)^+\right)}\right) \end{aligned} \tag{7}$$

If we assume in the final bargaining period that $p_f = p_s$, then we have to put the supplier profit function into the total profit maximisation (the supplier and buyer profits). Thus, the supplier strategy as a first mover needs to be optimised in order to find the optimum product price, as follows.

3.2 *Supplier' strategy (first mover)*

Suppose the suppliers act as a first mover and simultaneously announce the price at which they are prepared to sell their product and then the amount that they will sell. The buyer, on the other hand, makes a supply contract for the two suppliers after the incumbent supplier has had experience of bad quality (Lyon, 2006). Thus, inter-brand competition within the buyer outlet is allowed. Two main contract items are announced by the buyer, namely supply capability and flexible price as a result of innovation. The contract also covers an agreement on information exchange between the buyer and the suppliers where the buyer informs the suppliers of the module interfaces requirements. An example of this inter-changeability is the air conditioning unit of automobiles (Hata et al., 2001). There are some constraints in the case and piping for installation. The paper chooses three components which can be modularised for nine different types of air conditioner, namely heater, ventilator and air conditioner. Thus, by making modular design in these functions then the air conditioning unit flexibility can be improved. The two suppliers need to be informed fully by the buyer of the standardisation requirements. Furthermore, the new supplier has also been informed by the buyer about the incumbent supplier's price. Thus, a Bertrand-like competition is used in this analysis by considering that the suppliers will set the prices first simultaneously and then in the second stage they observe the demand uncertainty σ and thus the buyer demands size q_1 and q_2 as well as standard deviation σ_s. The benefits of this modified Bertrand game are that the supplier can get higher product prices p_1 and p_2 from the buyer and the buyer can observe the suppliers' supply promptness ε_s. Furthermore, it provides a comparison result with the existing literature on dual sourcing and also provides a foundation for future studies, where it would be possible to distinguish between two effects of the substitutability degree between products in increased competition between single-flexible product duopolists. Such an analysis would be useful in studying the product line decisions of multi-product buyers. Examples of industries that meet these criteria include manufacturers of computer motherboards for several series of processors and memory chips, computer cooling systems and the electronic fuel injection (EFI) systems of several car series.

Thus the modified Bertrand model is represented as

$$q_1 + \varepsilon_s = b - p_1 + \gamma . p_2 + \sigma \tag{8}$$

$$q_2 + \varepsilon_s = b - p_2 + \gamma . p_1 + \sigma \tag{9}$$

Where b is the buyer total market, p_1 and p_2 are the prices of Suppliers 1 and 2. γ in equation (8) and (9) also represents product substitutability γ. q_1 and q_2 are the buyer demands from Suppliers 1 and 2. We can see that if the total market demand uncertainty σ increases, then the product demand uncertainty $q_1 + \varepsilon_s$ also increases due to the increase in the suppliers' supply uncertainty ε_s. Furthermore, the increasing of product demand uncertainty forces the buyer to encourage innovation in the suppliers by increasing the product substitutability γ, which triggers the suppliers to become more competitive in moving from monopolists to duopolists and which increases the product price regardless of product demand reduction. Thus, the buyer and suppliers can be better off if they set a higher price.

The notable point here is that flexibility enables the buyer to delay product differentiation by putting flexible components close to the order execution point, so that the buyer can make to stock for the component. Thus, innovation between two suppliers in terms of commonality degree and product platform modularity is required to postpone product differentiation.

To simplify the calculation, then $b + \varepsilon_b$ and $q + \varepsilon_s$ can be replaced by ε and q. Thus, equations (1) and (2) can be reformulated as

$$q_1 = \varepsilon - p_1 + \gamma . p_2 \tag{10}$$

$$q_2 = \varepsilon - p_2 + \gamma . p_1 \tag{11}$$

q_1 and q_2 is equal at Nash Equilibrium where the suppliers' prices are also assumed to be equal to encourage innovation and produce flexible products. Thus, equations (10) and (11) can be reformulated as

$$q_1 = q_2 = \varepsilon - (1-\gamma)\, p_f \tag{12}$$

To illustrate, we suppose two suppliers make an auction and the buyer makes an opening bid and afterwards the suppliers cooperate with one another on the chosen price and product substitutability. Restricting attention to the strategic moves of this two-stage game, we shall see that whether the suppliers choose a cooperative or a non-cooperative strategy, the bidding price is used by the buyer to optimise the buyer's selling price, where it is finally used by the suppliers to optimise their total costs. If the buyer wants the suppliers to be innovative, then the buyer can apply threats and/or promises by playing demand uncertainty $\varepsilon_b \leq 1$. Strategic moves are required to guarantee the credibility of the actions ($\varepsilon_b = 0$, $\varepsilon_s = 0$). Thus, the suppliers and buyer need to formulate their payoffs before they start to announce their threats and promises in the delivery contract. From this point on, the game is started from Stage 2, where the suppliers and the buyer decide their contract price, as follows.

Stage 2 The suppliers and buyer optimise their agreed auction price.

Suppose the buyer and the suppliers are two different organisations. Thus, neither the supplier nor the buyer agrees to suffer by losing profit. Below is given the joint optimisation by presenting mutual profits between the buyer and supplier

$$\begin{aligned} &\max_{p_s} \pi_{tot} = \pi_b + \pi_s \\ &\max_{p_f} \pi_{tot} = \left(\frac{\varepsilon_b}{2} - \frac{p_f}{2.}\right) . \left(\frac{\varepsilon_b}{2.(1-\gamma)} - \frac{p_f}{2}\right) + \left(\varepsilon_b - (1-\gamma)\, p_f\right)\left(p_f - c\right) \\ &\text{s.t } \left(p_f - c\right) \geq 0 \end{aligned} \tag{13}$$

Where π_b is the buyer profit and π_s is the supplier profit.

Solving that equation for p_f, one obtains

$$p_f = \frac{\dfrac{3\varepsilon_b}{4} - \dfrac{\varepsilon_b}{4.(1-\gamma)} + (1-\gamma).c}{\left(2(1-\gamma) - \dfrac{1}{2}\right)} \tag{14}$$

Equation (14) describes the compromise price between the buyer bid price and suppliers' auction price. This equation is also developed in order to respond to Anton and Yao's (1989) argument about supplier collusion. We can see that the increasing of demand uncertainty is also a disadvantage to the buyer by increasing the suppliers' product price, while the increasing of product substitutability will give benefit to the suppliers' product price p_f. Product substitutability and demand uncertainty are the two critical decisions in supplier and buyer cooperation.

Stage 1 The suppliers optimise their total costs.

From Stage 2, we have information that the selling prices of the two suppliers are equal, thus, in the first stage we can find

$$\max_c \left(\varepsilon_b - \frac{(1-\gamma)\left(\frac{3\varepsilon_b}{4} - \frac{\varepsilon_b}{4.(1-\gamma)}\right)}{\left(2(1-\gamma)-\frac{1}{2}\right)} - \frac{(1-\gamma).c}{\left(2(1-\gamma)-\frac{1}{2}\right)} \right).c \tag{15}$$

By optimising (15) against c and substituting ε_b by equation (1) or (2), then the supplier total cost c can be found as

$$c = \frac{\varepsilon_b\left(2(1-\gamma)-\frac{1}{2}\right)}{2(1-\gamma)} - \frac{\left(\frac{3\varepsilon_b}{4} - \frac{\varepsilon_b}{4.(1-\gamma)}\right)}{2} \tag{16}$$

The total costs c can be categorised as the total costs at over-estimation $c_{(\varepsilon-b)^+}$, at under-estimation $c_{(b-\varepsilon)^+}$ and at the buyer's demand $c_{(\varepsilon=b)}$.

Stage 1 shows that the increasing of product substitutability (γ) will increase the suppliers' total costs. Similarly, higher demand uncertainty will increase the suppliers' total costs. Obviously, this statement is correct since higher product substitutability will make the suppliers more innovative and put more resources into R&D. The effects of demand uncertainty and product substitutability have a positive impact on innovation and flexibility by pushing the suppliers to develop highly flexible products in order to reduce demand uncertainty. Thus, from the buyer's point of view, it is very easy to change the product to another supplier whenever the other product is not available.

3.3 *Supplier payoff calculation*

Suppliers' payoffs can be determined by combining product price p_s, total cost c and buyer demand size q_s as

$$\pi_{s1}(\varepsilon_s = 0; \varepsilon_b = 0) = \left(p_{s(\varepsilon=b)} - c_{(\varepsilon=b)}\right).q_s\big|_{(\varepsilon=b)} + I \tag{17}$$

$$\begin{aligned} \pi_{s2}(\varepsilon_s = 0; \varepsilon_b \geq 1) = (1-\alpha)q_s\big|_{(\varepsilon-b)^+} \cdot \left(p_{f(\varepsilon-b)^+} - c_{(\varepsilon=b)}\right) \\ +\alpha.q_s\big|_{(b-\varepsilon)^+} \cdot \left(p_{b(b-\varepsilon)^+} - c_{(\varepsilon=b)}\right) + I \end{aligned} \tag{18}$$

$$\pi_{s3}\left(\varepsilon_s \geq 1;\varepsilon_b = 0\right) = \left(1-\alpha\right) q_s\big|_{(\varepsilon-b)^+} \cdot \left(p_{f(\varepsilon=b)} - c_{(\varepsilon-b)^+}\right) + \alpha . q_s\big|_{(b-\varepsilon)^+} \cdot \left(p_{f(\varepsilon=b)} - c_{(b-\varepsilon)^+}\right) - p \tag{19}$$

$$\pi_{s4}\left(\varepsilon_s \geq 1;\varepsilon_b \geq 1\right) = \left(1-\alpha\right) . q_s\big|_{(\varepsilon-b)^+} \cdot \left(p_{f\left(\varepsilon_b \geq 1(\varepsilon-b)^+\right)} - c_{(\varepsilon-b)^+}\right) + \alpha . q_s\big|_{(b-\varepsilon)^+} \cdot \left(p_{f\left(\varepsilon_b \geq 1(b-\varepsilon)^+\right)} - c_{(b-\varepsilon)^+}\right) - p \tag{20}$$

Where $\pi_{s1}\left(\varepsilon_s \leq \varepsilon;\varepsilon_b \leq \varepsilon\right)$ is the suppliers' profit at supplier uncertainty $\varepsilon_s = 0$ and the buyer demand uncertainty $\varepsilon_b = 0$. $p_{s(\varepsilon_s \leq \varepsilon)}$ is the suppliers' selling price to the buyer at suppliers' total costs $c_{(\varepsilon_s = 0)}$ in order to produce order size $q_{s(\varepsilon_s = 0)}$. Incentive is given to the suppliers by considering $\varepsilon_s = 0$. The same meaning is also applied to (18). Conversely, $\pi_{s3}\left(\varepsilon_s \geq 1;\varepsilon_b = 0\right)$ in (19) denotes the suppliers' profit at supplier uncertainty $\varepsilon_s \geq 1$ and the buyer demand uncertainty $\varepsilon_b = 0$, $p_{s(\varepsilon_s = 0)}$ is the suppliers' selling price to the buyer at suppliers' total costs $c_{(\varepsilon_s \geq 1)}$ in order to produce order size $q_{s(\varepsilon_s \geq 1)}$. A penalty is imposed on the suppliers by considering $\varepsilon_s \geq 1$. Equation (20) has the same explanation.

Equations (17)–(20) can be used for all strategic couples in the strategic form (see Figure 1). The value of p_s, c and q_s depend on the buyer strategy. Thus, in the section below the buyer strategic moves in applying threats and promises are elaborated.

4 Problem example and data analysis

Studies on dual sourcing have been able to shed light on purchasing as a strategic decision. In addition, they have underscored the importance of strategic thinking in the sourcing decision by considering that the activity should be assigned to critical activities which give most contribution to the final product.

This section will be used to show the applicability of the analytical model. First, the required data (demand uncertainty in the market ε, product substitutability degree γ, buyer order uncertainty to the supplier ε_b), are used to determine the value of penalty cost p and incentive cost I to the supplier, where they are finally used to decide the buyer and suppliers' profits at $\varepsilon_b = 0$ and $\varepsilon_s = 0$ or π_{b1} and π_{s1}, at $\varepsilon_b \geq 1$ and $\varepsilon_s = 0$ or π_{b2} and π_{s1}, at $\varepsilon_b = 0$ and $\varepsilon_s \geq 1$ or π_{b1} and π_{s2}, at $\varepsilon_b \geq 1$ and $\varepsilon_s \geq 1$ or π_{b2} and π_{s2}.

Let us suppose the supply contract mentions that the buyer must fulfil demand at 1,000 units per month. This value means that the cumulative buyer's demand information error must be less than one within one month. Thus, by applying equations (2), (14) and (16) we have the following results:

Table 1 Buyer selling and buying prices, suppliers' total costs c according to demand uncertainty (ε_b) and product substitutability γ

ε	γ	$\varepsilon_b \geq 1(\varepsilon - b)^+$	$(\varepsilon_b = 0)$	$\varepsilon_b \geq 1(b - \varepsilon)^+$	$c(b - \varepsilon)^+$	$c(\varepsilon_b = 0)$
1000	0.1	1001	1000	999	250	250
1000	0.2	1001	1000	999	250	250
1000	0.3	1001	1000	999	250	250
1000	0.4	1001	1000	999	250	250
1000	0.5	1001	1000	999	250	250
1000	0.6	1001	1000	999	250	250
1000	0.7	1001	1000	999	250	250
1000	0.8	1001	1000	999	250	250
1000	0.9	1001	1000	999	250	250
$c(\varepsilon - b)^+$	$p_f(\varepsilon_b \geq 1(b - \varepsilon)^+)$	$p_f(\varepsilon_b = 0)$	$p_f(\varepsilon_b \geq 1(\varepsilon - b)^+)$	$p_b(\varepsilon_b \geq 1(b - \varepsilon)^+)$	$p_b(\varepsilon_b = 0)$	$p_b(\varepsilon_1 \beta \geq 1(\varepsilon - b)^+)$
249.8	190.4	190.2	190.0	–9629.3	–9619.7	–9610.0
249.8	216.1	215.9	215.7	–4572.8	–4568.2	–4563.6
249.8	242.3	242.1	241.8	–2852.1	–2849.2	–2846.4
249.8	262.2	261.9	261.6	–1978.2	–1976.2	–1974.2
249.8	250.3	250.0	249.8	–1501.5	–1500.0	–1498.5
249.8	83.4	83.3	83.2	–1501.5	–1500.0	–1498.5
249.8	–1584.9	–1583.3	–1581.8	–4599.8	–4595.2	–4590.6
249.8	5505.5	5500.0	5494.5	9759.8	9750.0	9740.3
249.8	5922.6	5916.7	5910.8	10732.9	10722.2	10711.5

Table 1 exhibits the calculation results for the suppliers' total costs c, the suppliers' product price p_f and the buyer's selling price p_b, which is calculated by considering three situations: over-estimation of demand uncertainty $\varepsilon_b > 1(\varepsilon - b)^+$, correct estimation $\varepsilon_b = 0(\varepsilon = b)$, and highly accurate estimation $\varepsilon_b < 1(b - \varepsilon)^+$. This example takes one unit over or under the predetermined supply contract to show the sensitivity of the developed model, at least the difference between real demand uncertainty ε and forecast demand uncertainty ε_b. We can see from Table 2 that our model is highly sensitive by giving different values on all decision parameters (the suppliers' total costs c, suppliers' product price p_f and buyer's selling price p_b).

Table 1 also shows us that high product differentiation (low substitutability degree) has effect on the lowering of product price from the suppliers to the buyer. This situation implies that the suppliers and the buyer prefer to be more innovative in dual sourcing. This situation is supported by Anton and Yao's (1992) conclusion that collusion by suppliers can reduce innovation by reducing the product price. Conversely, this paper proves that high cooperation can give benefit to the buyer and suppliers by increasing the product price as well as product substitutability. The increasing of product substitutability should be followed by an increase in innovation. Indeed, by giving a higher price to a highly substitutable product, the buyer wants them to be more integrated. This is also one kind of innovation.

Obviously, from the buyer's point of view, supply sustainability is the main objective since strategic sourcing is related to a strategic item which has high risk if it is not available. Thus, equation (3) is used in the establishing of a penalty and incentive policy to the suppliers, as shown in Table 2 below.

In Table 2 we can see that the sum of supply quantities (Supplier 1 and 2) are at the closest total market demand size. Furthermore, the penalty and incentive are also lower because of the lower suppliers' production quantity.

Table 2 also shows that the penalty and incentive must be high enough that the buyer also suffers by imposing a penalty on the suppliers. The reason is that the buyer is forced into an unwanted strategy because of the suppliers' action. Furthermore, the penalty and incentive intention is also increased by the increasing of product substitutability, where it signifies that higher product substitutability must be able to reduce supply uncertainty.

Finally, the possible payoffs from the possible strategies of the buyer and suppliers can be summarised below by the following equations (4)–(7) and (17)–(20).

Table 3 shows that the suppliers' payoffs increase with the increasing of product substitutability. Similarly, the buyer's payoffs also increase. Furthermore, there is one situation where the buyer must make strategic moves as a second mover by restricting the suppliers' action of being non-cooperative and encourage innovation. Thus, the buyer can say 'I will be cooperative and innovative if the suppliers are also cooperative and innovative'. Likewise, 'I will be non-cooperative and non-innovative if the suppliers are also non-cooperative and non-innovative'. These statements are credible since the suppliers and buyer's profits will decrease dramatically when they become non-cooperative and less innovative.

Table 2 Buyer penalty and incentive policy

ε	γ	$\varepsilon_b \geq 1(\beta-\varepsilon)^+$	$(\varepsilon_b = 0)$	$\varepsilon_b \geq 1(\varepsilon-b)^+$	$q_c(b-\varepsilon)^+$	$q_s(\varepsilon=b)$	$q_s(\varepsilon=b)$	p	I
1000	0.1	1001	1000	999	830	829	828	206839	207004
1000	0.2	1001	1000	999	828	827	826	206446	206611
1000	0.3	1001	1000	999	831	831	830	207265	207431
1000	0.4	1001	1000	999	844	843	842	210335	210504
1000	0.5	1001	1000	999	876	875	874	218356	218531
1000	0.6	1001	1000	999	968	967	966	241232	241425
1000	0.7	1001	1000	999	1476	1475	1474	368087	368381
1000	0.8	1001	1000	999	−100	−100	−100	−24955	−24975
1000	0.9	1001	1000	999	409	408	408	101900	101981

Table 3 Buyer and supplier pay-offs

					Strategy I		*Strategy II*	
					Supplier	*Buyer*	*Supplier*	*Buyer*
					Cooperative	*Cooperative*	*Cooperative*	*Non-cooperative*
ε	γ	$\varepsilon_b(\varepsilon_b > \varepsilon)$	$\varepsilon_b(\varepsilon = \varepsilon_\beta)$	$\varepsilon_b(\varepsilon \geq \varepsilon_b)$	π_{s1}	π_{b1}	π_{s2}	π_{b2}
1000	0.1	1001	1000	999	157465	–8122551	157181	–8123663
1000	0.2	1001	1000	999	178437	–3953612	178196	–3954347
1000	0.3	1001	1000	999	200846	–2564703	200646	–2565342
1000	0.4	1001	1000	999	220528	–1884288	220357	–1884895
1000	0.5	1001	1000	999	218531	–1529500	218334	–1530069
1000	0.6	1001	1000	999	80475	–1528945	79943	–1529251
1000	0.7	1001	1000	999	–2333081	–44404450	–2338687	–4436459
1000	0.8	1001	1000	999	–549450	–425124	–550451	–424123
1000	0.9	1001	1000	999	2413556	1962720	2417976	1958328

					Strategy III		*Strategy IV*	
					Supplier	*Buyer*	*Supplier*	*Buyer*
					Non-cooperative	*Cooperative*	*Non-cooperative*	*Non-cooperative*
ε	γ	$\varepsilon_b(\varepsilon_b > \varepsilon)$	$\varepsilon_b(\varepsilon = \varepsilon_\beta)$	$\varepsilon_b(\varepsilon \geq \varepsilon_b)$	π_{s3}	π_{b3}	π_{s2}	π_{b2}
1000	0.1	1001	1000	999	–256525	–8138165	–49500	–8116212
1000	0.2	1001	1000	999	–234784	–3961319	–28152	–3950628
1000	0.3	1001	1000	999	–214032	–2569792	–6580	–2562852
1000	0.4	1001	1000	999	–200509	–1888103	10016	–1883001
1000	0.5	1001	1000	999	–218553	–1532639	0	–1528495
1000	0.6	1001	1000	999	–402270	–1531937	–160821	–1527802
1000	0.7	1001	1000	999	–3067720	–4446441	–2699302	–4434567
1000	0.8	1001	1000	999	–499078	–425355	–524056	–424235
1000	0.9	1001	1000	999	2207735	1963914	2309726	1958738

5 Managerial implications

Studies on strategic thinking in procurement have been argued for in some of the literature in dual sourcing. Nonetheless, these results give a new insight into managerial decisions on procurement. One notable result is that dual sourcing is strongly recommended to attract two suppliers to cooperate together without ignoring the suppliers' competition. Indeed, producing highly flexible products for the buyer can increase the profit level of the buyer as well as the suppliers. This paper complements the ideas of Anton and Yao (1992) by suggesting a solution for the buyer in applying strategic moves. Strategic moves will attract the two suppliers to be more innovative since they relate the suppliers' innovation with the inability to meet the buyer demand. If the suppliers do not make the innovation, then the buyer can move strategically by becoming non-cooperative $\varepsilon_b > \varepsilon$ (Table 3) and pay less (Table 1), so that the suppliers' profit margin will also reduce. On the other hand, the buyers will pay a much higher price to show their commitment to innovation. Furthermore, the buyer's strategy must be credible from the suppliers' point of view by applying strategic moves. The buyer can deliberately be more non-innovative and non-cooperative, regardless of the demand uncertainty minimisation effort, if the suppliers also ignore supply uncertainty. On the other hand, the buyer can also give an incentive when the supplier can reduce the supply uncertainty (Table 3).

One concern of the buyer is whether dual sourcing lowers the procurement cost when innovation is considered. This question was raised by Lyon (2006), who suggested dual sourcing application in government procurement. Lyon studied advanced technology procurement, where the numbers of potential suppliers are limited and assumes that the buyer has a higher bargaining power by putting forward quality and complexity problems as a motivation for dual sourcing, regardless of contract length and supply quantity. The possible reason for this result is that the author ignored the suppliers' innovation investment, so that incentive collection as a result of innovation was not discussed. The current paper, however, supports Lyon (2006) partially, by showing that dual sourcing lowers the procurement cost at a product substitutability degree of less than 0.7. Furthermore, more innovation reverses this trend. On the buyer side, this benefit comes from the higher selling price to the end customer at a high product substitutability degree, since the innovation content is also higher. In conclusion, buyers can ensure that they push suppliers to make the highest level of innovation without allowing the suppliers to collude together in ignoring innovation and selling at higher quantity. Furthermore, the suppliers' action in merely reducing innovation is not credible from the buyer point of view, because the buyer will not follow the strategy.

6 Conclusions and further research

This paper discussed the application of strategic thinking in dual sourcing by considering the effect of innovation. We may summarise the results derived from the model to answer the research questions, as follows.

1 The connection between dual sourcing procurement cost and innovation performance at the R&D phase of procurement is that innovation increases dual sourcing procurement cost because the buyer needs to compensate the suppliers' innovation to

induce competition. Furthermore, the application of lower penalty and incentive costs at a higher degree of innovation are intended to influence supply promptness and finally to induce the suppliers' innovation. Thus, the buyer's market positioning is also improved by offering a wide variety of products to the end customer. This conclusion is at odds with the previous literature on dual sourcing (Anton and Yao, 1992; Lyon, 2006) by regarding innovation as a competitive advantage.

2 Strategy formulation with respect to innovation can be split into two. The suppliers always make a commitment to be cooperative by considering the payoffs. On the other hand, the buyer can take benefit as a second mover to induce the suppliers' cooperation by applying strategic moves. The analytical results indicate that the suppliers will reduce information asymmetries, thereby inducing more aggressive bidding at the higher innovation effort. On the other hand, the buyer has more leverage on future contracts by changing the dimension of product quality to induce innovation. As a result, the suppliers are encouraged continuously to be more innovative and competitive.

3 Dual sourcing procurement with innovation is appropriate where the customer is quality sensitive, regardless of product price (for example, computer chips and mobile technologies).

The analytical model here focused on strategic thinking application in dual sourcing by considering innovation. In terms of future research direction, it would be necessary to investigate the possibility of applying strategic thinking in dual sourcing, where one of the suppliers assumes that the buyer is not the dominant customer. An example of this situation in industry is with computer fan suppliers. The fan is a critical component of the personal computer. If one buyer asks the suppliers to change the design by increasing the speed and reducing the power consumption of the fan, then the fan suppliers will not directly change the design without considering the contribution of the buyer to the suppliers' market share. Thus, it is difficult to attract a stronger supplier to maximise innovation. The possible solution is not only threats and promises, but also the commitment to use the fan in the entire product portfolio. The problem is that dual sourcing allows dual supplier application simultaneously. This is the future research area that should be investigated.

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APPENDIX D.

PAPER 3.4.6

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Designing supply chain by coordinating manufacturing process and product development process

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Abstract: Segregation of product development and manufacturing process creates an engineering problem in concurrent engineering application. Commonality analysis has never been used for solving this problem, but rather solely as a product development tool. This paper focuses on coordinating the manufacturing and product development process to produce supply chain agility. The purpose of this paper is to present a novel approach to managing the product development process by considering strategic safety stock allocation to decide on the customer order decoupling point. The new approach to commonality analysis by multi criteria decision making and vector analysis is developed by optimising the safety stock allocation. The results show that the safety stock allocation increases product commonality. Furthermore, it increases the whole product family profitability by lowering total costs. Product reconfiguration should be carried out in the future in considering safety stock placement. In terms of managerial implication, coordination between the manufacturing process and product development department facilitates supply chain design.

Keywords: MC; mass customisation; Manufacturing process; product development; supply chain; manufacturing strategy.

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1 Introduction

The need for mass customisation (MC) has replaced the current trend in manufacturing industry since the 1990s (Pine, 1993). Furthermore, nowadays the firm needs to be different not only in manufacturing, but also in marketing by satisfying the cumulative requirements of price, quality, flexibility and agility by applying information and operational technologies (Kumar, 2008; Vesanen, 2007). However, this trend has been slowly adopted by up to 1,124 articles within two decades (Kumar, Gattoufi and Reisman, 2008) even the trend to be exponentially growth.

Since the MC concept is emphasised in the marketing-customer interface (Vesanen, 2007) or in the product development and manufacturing process (Jiao and Tseng, 1996) separately, this concept underlines the importance of coordinating the development of product and manufacturing process design (Huang, 1996) within supply chains (SC) to enable concurrent engineering (Fixson, 2005; Fogliatto, Da Silveira and Royer, 2003; Hult and Swan, 2003). Engineering problems often follow as a result (Fine, 1998).

Without arguing against the previous literature, this paper, however, fills a gap in coordinating the development of product and manufacturing process design by formulating a commonality index according to the manufacturing process design to satisfy customer requirements such as price, flexibility and agility (Kumar, 2008). The coordination building takes effect in product design strategy where the manufacturer needs to optimise safety stock allocation (Graves and Willems, 2008) to solve the engineering problem, and at the same time maximise production flexibility by coordinating inventory and capacity management through push–pull manufacturing strategy so as to reduce shipping and inventory costs (Jammernegg and Reiner, 2007). Thus, the inclusion of inventory coordination into product design strategy will support the previous product commonality benefit of inventory reduction (Collier, 1982).

The purpose of this paper is to determine how the model should be interpreted in terms of action and implementation steps, and investigate the effect of coordinating the development of product design and manufacturing process design by meeting design requirements for the supply chain (Hilletofth, 2009). In particular, unlike most of the existing literature on product commonality analysis, we explicitly integrate product and process platform optimisation by adding manufacturing process optimisation into product commonality analysis to represent concurrent engineering in the light of agile supply chain (Sharifi, Ismail and Reid, 2006).

In addition to recent literature, vector analysis in CI building is a special feature of this paper in measuring how closely the customer requirements are met. In fact, this new approach demonstrates push–pull manufacturing strategy usability in product platform commonality analysis. The idea is to build CI by deciding on the degree of customer involvement in the manufacturing phase. This approach has been posited by Blecker and Abdelkafi (2007) in proposing a future research direction to provide an analysis of the effects of component commonality on the decoupling points. Thus, from the manufacturing process point of view, our research offers a good opportunity to investigate the manufacturing process capability effect on product development decisions.

This paper has been organised as follows. Section 1 introduces the motivation of the research. Section 2 elaborates the background of the research. Section 3 develops models of coordinating manufacturing process design and development of product design.

Section 4 explains the models by introducing one problem example and discussing the implications for managers. Section 5 explores the information behind the example results and discusses some future research opportunities.

2 Background of the research

Component commonality analysis was first presented by Collier (1981) and was re-discussed further by the same author (1982) and Eynan and Rosenblatt (1996) by taking into consideration the effect at the aggregate inventory level. Collier (1982) shows that a lower number of distinct components will reduce the total safety stock, which means that it will also reduce the product commonality. Similarly, Jiao and Tseng (1996) explain that both design and manufacturing concerns need to be considered in the commonality measure by arguing that a high commonality of processes would necessitate high commonality of the components involved.

In contrast to other investigations (Collier, 1981, 1982; Eynan and Rosenblatt, 1996; Jiao and Tseng, 2000a; Martin and Ishii, 1996; Siddique, Rosen and Wang, 1998; Wacker and Trelevan, 1986), Blecker and Abdelkafi (2007) propose a different commonality index, which comprises the commonality of common components and must-generic items, and the commonality of the product family with respect to options. The difference between this index and the previous literature is significant since it incorporates the selection probability of components, which also describes the customer preferences (Du, Jiao and Tseng, 2003). This paper considers that positive impact on the commonality level depends merely on generic items. In supporting the Blecker and Abdelkafi commonality index, Jones and Riley (1985) insist on customer order decoupling point (CODP) as a means of design for manufacturing.

Jiao and Tseng (1996), furthermore, broaden the concept of design for manufacturing by proposing design for mass customisation (DFMC), which optimises reusability/commonality, synthesises the product family architecture (PFA) and facilitates meta-level integration throughout the design process. The authors mention that DFMC enables the manufacturer to integrate systems within the product development process. This concept, furthermore, is enhanced by Jiao and Tseng (2000b) by mapping the functionality, behavioural and structural perspective of PFA to represent different phases of product development integration. This mapping illustrates the multi-dimensional decision making process of product architecture development (Tseng and Du, 1998). Thus, the description of customers and their requirements have to be defined in order to analyse the functional requirements for obtaining knowledge about the functional structure and technical structure design of product family structure (Agard and Kusiak, 2004).

Related to the approaches of Jiao and Tseng (2000a) on PFA, Fine (1998) and Fixson (2005) offer a product-operations strategy combination by considering three decision domains, namely, product, process and supply chain domain decisions. The last author cites the work of Ulrich (1995) in assessing the product architecture from its functionality and interface characteristics. Since it is a wider perspective of the commonality concept, however, this paper does not provide in-depth analysis of the process and supply chain domain impact, but instead gives a general description of the coordinated design decision. Thus, supply chain agility in terms of process alignment, network integration and market sensitivity can be achieved so as to obtain competitive advantage over competitors' supply chains (Faisal, Banwet and Shankar, 2007; Jones and Riley, 1985).

Taking into account the importance of a product-operations strategy combination by considering product, process and supply chain domain decisions, Graves and Willems (2000) develop a strategic stock placement in the supply chain model in reducing inventory cost and giving 100% guaranteed lead times. The same authors also discovered that the model was capable of determining agile supply chain by dynamically changing safety stock level as demand changes (Graves and Willems, 2008). The idea can be extended to production flexibility by achieving product and process flexibility to minimise production delay and maximise product mix (Abdel-Malek, Areeratchakul and Otegbeye, 2006). Thus, production time and delivery time need to be optimised in terms of the production cycle in a multi-stage production system with quantity varying between a minimum and a maximum value for each delivery (Bahroun, Campagne and Moalla, 2007).

Recently, Sanchez (2002) has studied the collaboration of product and process that make up the platform. In other words, the company should develop such a platforming strategy that enables it to improve the variety, and at the same time increase the reliability of the manufacturing process by increasing the service level. To embody the idea, product architecture decisions have to be made jointly and simultaneously with process architecture decisions. Furthermore, costs are not defined solely by bills of materials (BOMs) for specific product models, but have to be defined 'systemwide' with reference to all development, production and supply chain costs that are incurred in developing and realising new product variations over the lifetime of the platform. Thus, assessment and improvement of a product family by focusing on various aspects such as modularity, cost, commonality and variety (Alizon, Shooter and Simpson, 2007) could possibly be used for increasing the service level and reducing procurement cost through production and product process redesign (Fixson, 2007).

This present paper looks to fill a gap between collaborative product process platform development (Sanchez, 2002; Fixson, 2005) and component commonality analysis (Collier, 1981, 1982; Eynan and Rosenblatt, 1996; Jiao and Tseng, 1996) in developing a platforming strategy and manufacturing process by increasing the CI level and reducing total costs. CI is used to develop a platforming strategy that represents a degree of platform flexibility and CODP that represents manufacturing process design. Thus, it can support a supply chain design for achieving agility by focusing on supply chain characteristics and dynamics through company capability, supply chain and product feature assessments (Sharifi et al., 2006).

3 Model development

This section is composed of three subsections, namely, manufacturing process design, cost structure and parameters, and product commonality index development. Manufacturing process design (Section 3.1) details how to allocate safety stock to decide on CODP so that it optimises total cost structure (Section 3.2) and finally improve the product commonality degree by analysing product commonality index (Section 3.3). Each subsection is detailed as follows.

3.1 Manufacturing process design

We solve the manufacturing process design by decomposing the multi-stage supply chain strategic inventory location model into *J*-stages, where *J* is the number of workstations in the supply chain and there is one stage for each node. For each node-*j*, we define μ_j^* to be the optimum service rates and W_j to be the optimum service times that are used to explain strategic inventory allocation. Beforehand, μ_j and W_j need to be optimised against system parameters such as demand rate at stage-*j* λ_j, demand inter-arrival times and service times standard deviation at stage-*j* σ_{A-j} and σ_j, respectively, and utilisation factor ρ_j to inform us whether in our order there is a delay/backorder at stage-*j*, or not.

We model manufacturing process according to GI/G/1 queue model. The reason is that the demand inter-arrival and processing rate are not stationary and are just barely less than one $(1-\varepsilon)<\rho<1$ or are equal to or greater than one $(\rho \geq 1)$. This model closely represents the real situation in MC operations where common product platform increases process flexibility and the number of possible product configurations. Thus, common product platform makes manufacturing facility busier and has higher utilisation. This model closely represents demand uncertainty within mass customised production.

By using this model and following Little's formula (see Gross and Harris, 1974), total customers in the system at stage-*j* N_j can be interpreted as

$$N_j = \frac{\lambda_j^2 . \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2 \cdot \left(1-\rho_j\right)} + \rho_j \tag{1}$$

σ_{A-j} and σ_j in Equation (1) denote the demand inter-arrival rate standard deviation and service rate standard deviation at stage-*j*. σ_{A-j} can be found as maximum difference between average inter-arrival time $(1/\lambda_j)$ and maximum inter-arrival time at maximum demand during net replenishment time $1/(D_j(\tau))$ or $\sigma_{A-j} = (1/\lambda_j) - (1/D_j(\tau))$. Demand during net replenishment time is obtained by considering that safety stock should be covered only in this period because after production is finalised then the customer can get the product immediately. σ_{D-j} denotes demand rate standard deviation at stage-*j* and supposing that σ_{ij}^2 is inbound service variance and σ_{T-j}^2 is production process variance at stage-*j*. In finding service rate standard deviation σ_j, we assumed that between inbound service time standard deviation σ_{ij} and production process time standard deviation σ_{T-j} are independent. The reason is that σ_{T-j} depends on the number of customer order and σ_{ij} depends on the upstream stage $-i$ service rates standard deviation. These two processes are independent because they are two different firms. Finally, we formulate service rate standard deviation σ_j as $\sigma_j = \sigma_{(m+p)-j} = \sqrt{\sigma_{ij}^2 + \sigma_{T-j}^2}$.

Production process standard deviation σ_{T-j} can be assumed to equal σ_{A-j} by considering that each stage will produce to order. Inbound service time standard deviation σ_{ij} can be obtained from the service rate variance at its upstream stage-*i* or σ_{B-i} for $i = 1, 2, \ldots, j-1$ where stage-*i* is an adjacent node to stage-*j*. We define inbound service time standard deviation σ_{ij} as $\sigma_{ij} = \max\{\sigma_{ij}, \max\{\sigma_i \mid i : (i.j) \in A\}\}$. Exceptionally, σ_{ij} for most upstreams are known parameters since this standard deviation is caused by external factors of the supply chain, for example suppliers of most upstreams.

On average, stage-*j* places an order equal to $\Phi_{ij}\lambda_j$ where Φ_{ij} denotes arc $(i, j) \in A$ from downstream stage-*j* to upstream stage-*i* for which $\Phi_{ij} > 0$. Stage-*j* cannot start production to replenish λ_j until all inputs have been received; thus, we have $W_j = \max\{W_i \mid i : (i.j) \in A\}$ where W_j and W_i for $i = 1, 2, \ldots, j-1$ denote service time and optimum inbound service time for stage-*j*.

We do not permit $W_j > \max\{W_i \mid i : (i.j) \in A\}$ to avoid excess inventory and/or delay the orders to the suppliers so that idle capacity can be eliminated. Thus, we define inbound service time W_j, that is $W_i + T_j = W_j$ as $W_i = \max\{W_j - T_j, \max\{W_i i : (i.j) \in A\} |\}$. Thus, with regard to the G/GI/1 queue system, W_i is equal to waiting time in a queue

$$W_{q-j} \leq \frac{\lambda_j \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2\left(1 - \rho_j\right)}.$$

Since W_{q-j} is the maximum waiting time in a queue, then the following condition is applied to decide on W_i

$$W_i \leq W_{q-j} \leq \frac{\lambda_j \left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2\left(1 - \rho_j\right)} \tag{2}$$

In supporting concurrent engineering, component supply variance information sharing is needed to compose push–pull manufacturing strategy; thus, this information can be obtained from the component factory and we assume in this paper at a certain amount. In addition, penalty cost C_{W-j} and service cost C_{T-j} are also measured as well as customer demand and its standard deviation for each product variant for allocating stocks. Thus, cost function is developed in order to determine our optimum decision, as follows

$$E(C)_j = C_{T-j}.\mu_j + C_{W-j}.N_j \tag{3}$$

Equation (3) can be generalised into

$$E(C) = C_{T-j}.\mu_j + C_{W-j}.\left(\frac{\lambda_j^2.\mu_j.\left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2.\left(\mu_j - \lambda_j\right)} + \rho_j\right) \tag{4}$$

Equation (4) can be optimised according to the service rates for each node μ_j so that we have

$$C_{T-j}+\frac{\left(\sigma_{A-j}^{2}+\sigma_{j}^{2}\right).C_{W-j}}{2.\left(\mu_{j}-\lambda_{j}\right)}-\frac{\left(\sigma_{A-j}^{2}+\sigma_{j}^{2}\right).C_{W-j}.\mu_{j}}{2.\left(\mu_{j}-\lambda_{j}\right)^{2}}=0 \tag{5}$$

$$\mu_{j}=2.\lambda_{j}\pm\frac{\sqrt{2.\left(\sigma_{A-j}^{2}+\sigma_{j}^{2}\right).\lambda.C_{W-j}.C_{T-j}}}{2.C_{T-j}} \tag{6}$$

The two results of Equation (6) can be used to decide on base stock location by considering the least non-negative μ_j value at stage-*j*. This decision is used to calculate the optimum service time of each stage as $W_j = (\mu_j / \lambda_j).W_{q-j}$ and so we have maximum production time T_j as $T_j = W_j - W_{q-j}$.

In the case of a busy production facility as the second condition $(W_j > W_i)$, it is better to delay the orders to the suppliers by $W_{q-j} - W_i$. This suggests a different approach to Graves and Willems (2000) in satisfying a 100% service level by finding the maximum waiting time in a queue as production time T_j. Finding T_j satisfies the maximum possible demand over the net replenishment time τ for stage-*j* where it is replenishment time $W_i + T_j$ minus its service time W_j or $\tau = W_i + T_j - W_j$.

Following the formulation of Graves and Willems (2000) for the expected inventory $E(I_j)$ that represents the safety stock held at stage-*j*, then $E(I_j)$ can be found as the difference between cumulative replenishment and cumulative shipment, as follows

$$E(I_j) = D_j(\tau) - \lambda_j(\tau) \tag{7}$$

$$D_j(\tau) = \tau.\lambda_j + z_j.\sigma_D.\sqrt{\tau} \tag{8}$$

Equation (7) expresses the expected safety stock at maximum possible demand by finding the demand bound $D_j(\tau)$ where it is equal to maximum stock during τ at a certain level of customer service level at stage-*j* z_j (Graves and Willems, 2000). It is possible to get $E(I_j) = 0$, which means we can manage stage-*j* as make-to-order (MTO) instead of make-to-stock (MTS). Our model extends Graves' and Willems' (2000) strategic safety stock allocation by adding production time as the third variable that is optimised. Furthermore, without arguing the previous algorithm for holding cost at stage-*j* h_j minimisation, we use G/GI/1 queueing model to represent non-stationary demand and for finding the optimum guaranteed service time and production time. The reason is to provide tactical decision support for inventory managers to meet inventory cost minimisation and to coordinate replenishment. Guaranteed service time for stage $j-1$ optimisation automatically guarantees the inbound service time for stage *j*, where if it is combined with the optimised T_j, then gives guaranteed service time for stage *j* at minimum waiting time C_{W-j} and service cost C_{T-j}. Thus, we can meet costs and service time optimisation.

3.2 Cost structures and parameters

To analyse the product commonality index, first we consider the cost of product portfolios, which is computed in a top-down manner based on product family demand parameters. The cost model can take into account various cost parameters such as batch sizes and facilities investment.

Considering manufacturing process design, the total costs for stage-j can be formulated as

$$\mathrm{TC}_j = C_{p(j)}.\lambda_j + C_{Oj}\frac{\lambda_j}{q_j} + \sum_{i=1}^{j-1}\mathrm{TC}_{ij}.\Phi_{ij}.\lambda_j + C_{S(j)}.\frac{\lambda_j}{q_j} + h_j.\mathrm{TS}_j + \frac{I_j}{\mathrm{PT}_j}\left(\frac{r_j.(1+r_j)^n}{(1+r_j)^n - 1}\right) \quad (9)$$

$$q_j = \sqrt{\frac{2.\lambda_j.C_O}{h}} \quad (10)$$

Below definitions are given of the notations in (9) and (10).

1 $C_{p(j)}$ is the production cost for stage-j

2 q_j is the order batch size for stage-j

3 $C_{S(j)}$ is the setup cost of components or parts for stage-j

4 TC_{ij} is component cost for stage-j

5 h_j is the holding cost for stage-j

6 I_j is the investment cost for stage-j

7 PT_j is the payback period for stage-j

8 r_j is the interest rate for stage-j.

From the above formulation, the cost model incorporates the investment for stage-j and its components are processed into the cost structure by including pay-out time PT_j and investment cost I_j at interest rate $-r_j$ as an additional depreciation cost, which is needed by the firm to reimburse the facility investment cost. Next, information from this section will be used by PDD to compose the product commonality index, as follows.

3.3 Component part commonality index development

We solve the manufacturing process design by decomposing the multi-stage supply chain strategic inventory location model into J-stages, where J is the number of workstations in the supply chain.

In supporting design by customer (Tseng and Du, 1998), we solve component part commonality index development by decomposing the product structure into J-stages, where J is the number of products and components within the bill-of-materials (BOM). Let us also suppose that each component at stage-i for $i = 1, 2, \ldots, j-1$ supports each customer preference in a different level, so we have p_{ir} as the preference level of component at stage-i to customer requirement-r. From the PDD department information, each of components at stage-*i* has a different level of preference for the product variant at stage-*j* by as much as p_{ij}. Customers choose their option by deciding on several criteria according to their degree of importance p_r. Then, we have the probability that a product-*j* is chosen by the customer by considering *R*-customer requirements and *j*-component variants as $p_j = \sum_{r=1}^{R} \sum_{i=1}^{j-1} p_{ir} \times p_r \times p_{ij}$. This probability is called the total contribution of product-*j*.

Furthermore, the value of the product at stage-*j* V_j, which describes the contribution of net profit of the product j, can be formulated as follows

$$\sum_{j \neq k} V_j = \sum_{j \neq k} \left[p_j \times \left(P_j . \lambda_j \right) - \mathrm{TC}_j \right] \tag{11}$$

where P_j is the component-*j* price. This value is useful for product classification, where it can be used by the purchasing department to formulate procurement strategy. A higher V_j denotes that the product is an important one. In contrast, a lower value signifies a less important product.

As should be expected by now, effective use of the revenue into part commonality measurement expresses the needs of the firm to determine the corresponding price for the required level of output. Thus, by considering demand at stage-*j* as a price function $p_j = a_j - b_j . \lambda_j$ and maximum market price a_j, then net profit at stage-*j* can be formulated as

$$\pi_j = p_j \lambda_j - \mathrm{TC}_j \tag{12}$$

The maximum market price $P_j^{\max}$ is assumed at $\lambda_j = 1$, and the product price is at a maximum level or it is equal to TC_j at $\lambda_j = 1$. The minimum market price P_j^{miu} is obtained from (12) by setting $\lambda_j = D_j$ and $\pi_j = 0$. D_j in this case is the maximum possible demand during service time W_j instead of the maximum demand over the net replenishment time $T_j + W_i - W_j$. The reason for using different demand time span is that in this case price must be set according to total demand during the whole service period by considering that price analysis is taken just after all orders from the previous service period have been delivered. Thus, by interpolating between $P_j^{\max}$ and P_j^{miu} against $\lambda_j = 1$ and $\lambda_j = D_j$, then the price of the product at stage-*j* at λ_j can be obtained as below

$$P_j = P_j^{\min} + \frac{D_j - \lambda_j}{D_j - 1} \left(P_j^{\max} - P_j^{\min} \right) \tag{13}$$

Determining the product and component price is intended to describe the total contribution of components to the family profitability. The price is of great importance to a manufacturer that has more variety in product variants. This importance lies in long term product development and marketing decisions. The product and marketing managers can decide which component should be developed in the future (Jiao and Tseng, 2000a) by considering the selling price. Furthermore, the value informs the firm about the importance of each component to the customers.

From the above description, the commonality index can be produced by mapping the service time, unit product prices and total costs onto the Cartesian coordinate for the plane $x-y-z$ to represent agility in terms of time W_j, quality P_j and total costs TC_j, respectively. Thus, we can decompose a vector into component vectors along each coordinate axis.

We assume that ideal product structure is composed of the variables minimum total costs $\min \mathrm{TC}_j$, minimum service time $\min W_j$ (in this case, it is assumed as T_j) and maximum quality $\max P_j$, to obtain the commonality index $\gamma_j = 1$. Thus, we can write our unit vector for ideal product (P) and existing product (Q) as:

$$P = \cos\alpha \left(\min W_j\right) + \cos\beta \left(\frac{\max V_j}{\lambda_j}\right) + \cos\gamma \left(\frac{\min \mathrm{TC}_j}{\lambda_j}\right) \tag{14}$$

$$Q = \cos\alpha \left(\mathrm{W}_j\right) + \cos\beta \left(\frac{V_j}{\lambda_j}\right) + \cos\gamma \left(\frac{\mathrm{TC}_j}{\lambda_j}\right) \tag{15}$$

where $\max V_j = p_j \times (P_j.\lambda_j) - \mathrm{TC}_j$

These three cosines are called the *direction cosines* of time W_j, quality P_j and total costs TC_j. Finally, the angle between three-dimensional vectors can be represented as

$$\gamma_j = \arccos\left[\frac{P_j.Q_j}{|P_j||Q_j|}\right] \tag{16}$$

where

$$|P| = \sqrt{\left(\min W_j\right)^2 + \left(\max P_j\right)^2 + \left(\min \mathrm{TC}_j\right)^2}$$

and

$$|Q| = \sqrt{\left(\mathrm{W}_j\right)^2 + \left(\mathrm{P}_j\right)^2 + \left(\mathrm{TC}_j\right)^2}$$

γ_j is called product substitutability for product variety-*j*, which signifies to what degree products in the product family can substitute for each other. Equation (16) shows us that higher contribution to product family p_T increases γ_j value.

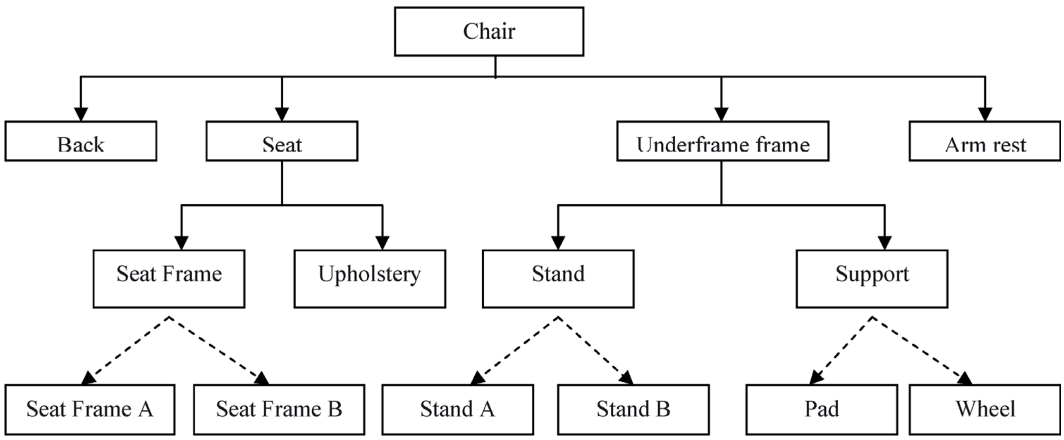
4 The problem

Our example is the design for a product family of office chair (see Du, Jiao and Tseng, 2000). The under-frame is composed of two modules – the stand and the support. The seat is composed of the upholstery and the seat frame. The customers are allowed to select whether or not a chair is turnable, moveable, and whether or not it has armrests. The example seemingly looks very simple to use to demonstrate our models.

From the engineering perspective, variants share the same general product structure, durable materials and design. Upholstery is a common module of this family. Both of the above two comprise the common base of the product family. The stand, support and seat frame are three distinctive modules. We notice that the variety of seat frame is derived from a variety without armrests. Support armrests are not a variety parameter of the end product. Hence, the variety of seat frame cannot be perceived by customers and is invisible at the end product level. The variety without armrests is embodied as a distinctive structural relationship between the modules of armrests and office chair.

A general product structure of the office chair product family can be depicted in Figure 1.

Figure 1 General product structure



4.1 Results

The first step in solving the problem is calculating how many product variants are in the product family. Since there are three parts that can be customised and each of them has two options, then the possible numbers of product variants are obtained from sum of factorials of components' varieties or $\text{Variety} = 2! \times 2! \times 2! = 8$ product variants. It is supposed that each product variant demand is independent. The symbol for components is first introduced to name the product variants, as in Table 1

Table 1 Components' symbol

Component	*Symbol*
Back	A
Seat Frame A	B
Seat Frame B	C
Upholstery	D
Stand A	E
Stand B	F
Pad	G
Wheel	H
Armrest	I

Table 2 Cost component calculation

Stage J	Component/ product	λ_j	μ_j	σ_{D-j}	σ_{A-j}	T_j	N_j	σ_{p-j}	σ_{m-j}	σ_j	C_{W-j}	C_{T-j}	Lower bound	Upper bound	W_i	W_j	W_{q-j}	$\mu_{j(\tau)}$	$D_{j(\tau)}$	$E(l_j)$	CODP Decision
12	Product ABDEGI	300	601	15.0	0.00016	3.0	899	0.00016	0.10	0.10	10	15	599	601	20.0	6.0	3.0	5,107	5,211	105	MTS
12	Product ABDEHI	250	501	12.5	0.00019	2.5	624	0.00019	0.10	0.10	10	15	499	501	20.0	5.0	2.5	4,381	4,469	88	MTS
12	Product ABDFGI	400	809	20.0	0.00012	20.6	101,245	0.00012	0.80	0.80	10	15	791	809	20.1	40.7	20.1	0	0	0	MTO
12	Product ABDFHI	300	608	15.0	0.00016	20.6	56,852	0.00016	0.80	0.80	10	15	592	608	20.1	40.7	20.1	0	0	0	MTO
12	Product ACDEGI	300	601	15.0	0.00016	3.0	899	0.00016	0.10	0.10	10	15	599	601	20.0	6.0	3.0	5,107	5,211	105	MTS
12	Product ACDEHI	200	401	10.0	0.00024	2.0	400	0.00024	0.10	0.10	10	15	399	401	20.0	4.0	2.0	3,604	3,676	72	MTS
12	Product ACDFGI	300	1,010	25.0	0.00010	20.5	158,381	0.00010	0.80	0.80	10	15	990	1,010	20.1	40.6	20.1	0	0	0	MTO
12	Product ACDFHI	800	1,613	40.0	0.00006	20.4	406,310	0.00006	0.80	0.80	10	15	1,587	1,613	20.1	40.5	20.1	0	0	0	MTO
11	Back	3,050	6,101	152.5	0.00002	2.0	8,371	0.00002	0.03	0.03	10	15	6,099	6,101	2.0	4.0	2.0	0	0	0	MTO
10	Seat	3,050	6,102	152.5	0.00002	3.0	23,251	0.00002	0.05	0.05	10	15	6,098	6,102	3.0	6.0	3.0	0	0	0	MTO
9	Underframe	3,050	6,101	152.5	0.00002	4.0	14,881	0.00002	0.04	0.04	10	15	6,099	6,101	4.0	8.0	4.0	0	0	0	MTO
8	Seat Frame A	1,250	2,501	62.5	0.00004	2.3	7,652	0.00004	0.07	0.07	10	15	2,499	2,501	10.0	12.3	6.1	0	0	0	MTO
7	Seat Frame B	1,800	3,602	90.0	0.00003	10.0	20,725	0.00003	0.08	0.08	10	15	3,598	3,602	10.0	20.0	10.0	0	0	0	MTO
6	Upholstery	3,050	6,101	152.5	0.00002	2.0	8,371	0.00002	0.03	0.03	10	15	6,099	6,101	2.0	4.0	2.0	0	0	0	MTO
5	Stand A	1,050	2,102	52.5	0.00005	10.0	11,016	0.00005	0.10	0.10	10	15	2,098	2,102	10.0	20.0	10.0	0	0	0	MTO
4	Stand B	2,000	4,021	100.0	0.00002	10.1	2,546,916	0.00002	0.80	0.80	10	15	3,979	4,021	10.0	20.1	10.0	0	0	0	MTO
3	Pad	1,500	3,000	75.0	0.00003	0.6	900	0.00003	0.02	0.02	10	15	3,000	3,000	8.0	1.2	0.6	11,100	11,445	345	MTS
2	Wheel	1,550	3,100	77.1	0.00003	0.6	961	0.00003	0.02	0.02	10	15	3,100	3,100	4.0	1.2	0.6	5,239	5,480	241	MTS
1	Armrest	3,050	6,103	152.5	0.00002	8.0	59,512	0.00002	0.08	0.08	10	15	6,097	6,103	8.0	16.0	8.0	0	0	0	MTO

Table 1 depicts the symbol of components for this paper, and the name of product variant is taken from the component's name that composes it. Table 2 depicts eight product variants (the first eight rows) and their components and $E(I_j)$ inventory allocation, as well as push–pull CODP decisions in considering services rates and inbound service and production rates. This paper assumes that σ_D for all products and components is 5%. Thus, by utilising Equations (1)–(6) we can decide on a strategic safety stock allocation to decide on push or pull CODP, as depicted in Table 2. It indicates that a longer replenishment time and higher supply standard deviation σ_{ij} create higher $E(I_j)$. This result implies that manufacturing and supply capability (T_j, W_i, σ_{ij}) have an important role in determining $E(I_j)$ allocation

Table 2 shows that different W_i has an effect on different levels of CODP, where longer procurement time needs safety stock allocation in the final product manufacturer.

The above result must be used in commonality index development by considering Equations (9)–(17) to calculate cost components, as follows.

Let us suppose a manufacturer receives customer requirements from the sales department. The firm's website contains customer preferences such as functionality, comfort, durability, price and flexibility. The website asks to the customer to rank the requirements according to their importance level by the application of analytical hierarchy process (AHP), by giving pairwise comparison between two preferences. The structure of the decision tree can be depicted as in Figure 2.

The customer specific information is then transferred to the central processing unit (CPU) to obtain the specific product, which meets the requirements at the closest level according to component variants. Once the information has been obtained, product development department (PDD) collects and analyses a brand new product commonality index for further improvement in product development design. Product information that is required by PDD are p_{kr} and p_{ik}, as follows

Further, information from Tables 3 and 4 can be used to compose γ_j by the following (11)–(16), as in Table 5

Figure 2 Decision tree for product variety analysis

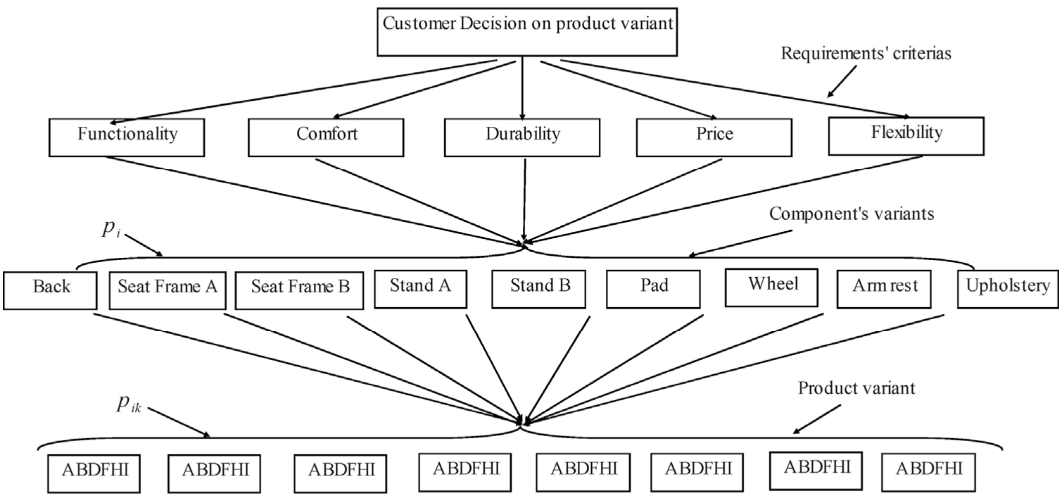


Table 3 p_r data from marketing department and p_{ir} data from PDD department

	Customer preference information from marketing department					*Normalised p_{ir} (%)*
	Functionality (%)	*Comfort (%)*	*Durability (%)*	*Price (%)*	*Flexibility (%)*	
			p_r			
Degree of importance	15	10	30	20	15	
Back	10	5	15	15	13	13
Seat Frame A	5	20	10	10	10	10
Seat Frame B	10	20	10	10	5	10
Stand B	15	5	15	15	20	15
Seat frame	10	10	20	15	5	14
Upholstery	20	15	5	5	13	10
Seat	10	5	5	5	10	7
Stand	5	5	5	10	7	6
Support	5	5	5	5	7	5
Stand A	5	5	5	5	5	5
Pad	5	5	5	5	5	5
Total	100	100	100	100	100	100

Table 4 Component $-i$ preference for product $-j$ p_{ij} data from product development department

	Back (%)	*Seat frame* (%)	*Upholstery* (%)	*Seat* (%)	*Stand* (%)	*Support* (%)	*Stand A* (%)	*Pad* (%)	*Stand B* (%)	
p_{ir}	13	14	10	7	6	5	5	5	15	
				p_{ij}						p_j (%)
Product ABDEGI	10	20	0	30	15	0	12.50	0	12.50	13
Product ABDEHI	13	13	0	15	0	0	20	30	10	12
Product ABDFGI	15	25	0	0	10	20	20	0	10	14
Product ABDFHI	10	20	0	0	0	20	20	15	15	13
Product ACDEGI	20	0	15	20	15	0	25	0	5	11

Table 4 Component $-i$ preference for product $-j$ p_{ij} data from product development department (continued)

	Back (%)	*Seat frame* (%)	*Upholstery* (%)	*Seat* (%)	*Stand* (%)	*Support* (%)	*Stand A* (%)	*Pad* (%)	*Stand B* (%)	
p_{ir}	13	14	10	7	6	5	5	5	15	
				p_{ij}						p_j (%)
Product ACDEHI	15	0	10	10	0	0	15	40	10	11
Product ACDFGI	20	0	10	0	10	30	10	0	20	13
Product ACDFHI	20	0	25	0	0	25	10	10	10	13
									Total	100

Table 5 CI calculation by using strategic safety stock allocation

Product name	$\min W_j$	$TC_j^{\min}$	$\max V_j$	W_j	TC_j	V_j	$P_j \cdot Q_j$	$\lvert P_j \rvert \lvert Q_j \rvert$	γ_j
Product AEDEGI	3.005	30.4	8,681	6	562.1	7774.7	67,512,816	67,672,277	0.998
Product AEDEHI	2.505	9.2	7,748	5	714.0	6938.6	53,765,330	54,042,677	0.995
Product ABDPGI	20.568	10.9	9,006	41	464.6	8065.1	72,637,404	72,753,095	0.998
Product AEDFHI	20.639	4.7	8,665	41	649.9	7759.5	67,236,641	67,469,246	0.997
Product ACDEGI	3.005	7.6	7,635	6	562.1	6837.1	52,202,421	52,374,257	0.997
Product ACDEHI	2.004	3.8	7,297	4	888.7	6535.1	47,691,629	48,127,184	0.991
Product ACDPGI	5.006	6.0	8,852	10	374.7	7927.4	70,176,477	70,252,633	0.999
Product ACDFHI	20.432	3.8	8,525	41	59472.2	7634.7	65,315,461	511,175,421	0.128
								γ average	0.89

Table 5 shows that lower TC_j takes effect in improving γ_j. Further, the effect of strategic safety stock allocation on total cost reduction can be shown as in Figure 3.

Figure 3 depicts that strategic safety stock allocation gives benefit in terms of total cost (products and components) reduction. Furthermore, the effect of this allocation on product development design can be shown through γ_j investigation, as follows.

Figure 3 Strategic safety stock allocations versus average inventory level total costs

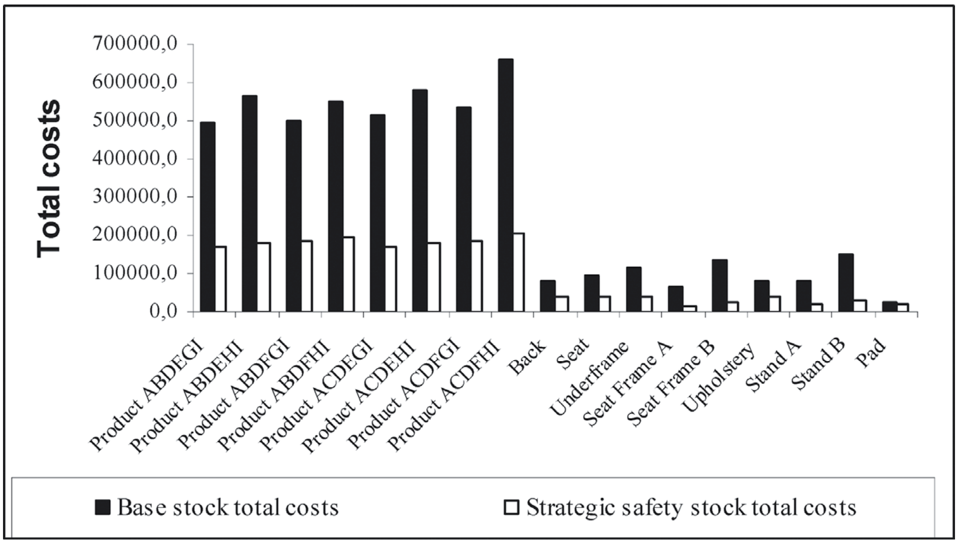


Table 6 CI calculation without applying strategic safety stock allocation

Product name	$\min W_j$	$TC_j^{\min}$	$\max V_j$	W_j	TC_j	V_j	$P_j \cdot Q_j$	$\lvert P_j \rvert \lvert Q_j \rvert$	γ_j
Product ABDEGI	3.0	30.4	8,681	6	1656.3	7648.7	66,452,172	67,941,266	0.978
Product ABDEHI	2.5	9.2	7,748	5	2263.4	6826.1	52,908,302	55,719,152	0.950
Product ABDFGI	20.6	10.9	9,006	41	1244.0	7934.3	71,468,689	72,328,393	0.988
Product ABDFHI	20.6	4.7	8,665	41	1839.4	7633.8	66,152,578	68,037,168	0.972
Product ACDEGI	3.0	7.6	7,635	6	1719.9	6726.3	51,365,217	53,004,267	0.969
Product ACDEHI	2.0	3.8	7,297	4	2911.8	6429.2	46,926,387	51,502,766	0.911
Product ACDFGI	5.0	6.0	8,852	10	1068.7	7799.0	69,043,244	69,682,070	0.991
Product ACDFHI	20.4	3.8	2,525	41	58508.3	7511.0	64,256,856	502,890,415	0.128
								γ average	0.86

Suppose that all of the product variants and components are managed by using standard inventory management (base stock and safety stock). Thus, the γ_j calculation for non-optimised safety stock allocation can be shown as in Table 6.

By comparing Tables 5 and 6, we can see that CODP management through strategic stock allocation can improve product commonality by increasing the γ_j value from 0.86 to 0.89. The small positive change in commonality signifies that components and products are used at almost equal opportunity.

4.2 Managerial implications

Although the application of the manufacturing process design and product development design integration have provided very preliminary findings on how product platform commonality degree can be assessed, it can, nevertheless, be used as a powerful decision support system.

Similar commonality index proposed in previous literature (Blecker and Abdelkafi, 2007; Collier, 1981, 1982; Eynan and Rosenblatt, 1996; Jiao and Tseng, 1996) undoubtedly focused on product architecture designs, since the manufacturing process design is separately discussed (Jiao and Tseng, 1996). This suggests that the allocation of strategic safety stock to decide on push–pull CODP is idiosyncratic to a particular product architecture design. Manufacturing process performance is based on the level of customer involvement in the product development process, and product development process performance is based on the way in which products can be manufactured and recombined into new configurations without losing functionality and performance. Thus, optimising the safety stock facilitates product manufacturability as well as acceptability in terms of customer requirements by linking to the product development process.

For practitioners, a strategic safety stock allocation to decide on CODP and γ_j measurement models is valuable, as they highlight various managerial and strategic implications of design for supply chain decisions. These decisions are usually based on the firm's vision on supply chain agility (Sharifi, Ismail and Reid, 2006). When the framework of mapping out a dynamic and structured approach for developing agile supply chains is understood in a systematic manner, strategic safety stock allocation and γ_j measurement models facilitate decision making with regard to product, company and supply chain factors. The decision making process facilitates coordination between the manufacturing process and the PDD so as to enhance knowledge sharing and trust.

In addition to concurrent engineering, concentrating on product development design solely causes operation problems. The effect of this assumption is that a process or product is optimised by assuming that the highest commonality in either product or process would reduce the lead times and at the same time the inventory level. This assumption seems to make sense even though it also enlarges the gap between product development and manufacturing processes at different factory locations. Blecker and Abdelkafi (2007), conversely, maximise customer expectation by allowing the probability of the component variants to be chosen by customers. However, this paper has just focused on the product design area, without giving an opportunity to the manufacturing process to reconfigure the strategic safety stock allocation and CODP in order to guarantee the lead times. Thus, information sharing related product development (i.e. product design, material and product specifications) and manufacturing process (i.e. holding cost, inventory level, production capacity, production cost and manufacturing process capability) are required along the supply chain. This can be applied by applying Vendor Managed Inventory (VMI), Collaborative Planning, Forecasting and Replenishment (CPFR) or Radio Frequency Identification (RFID) to facilitate concurrent engineering.

4.3 Discussion of the models

It is common in the literature that modular design or common components is an enabler for product customisation. This section gives an insight for product managers into the validity of the term. This section, in fact, supports supply chain design by investigating the effect of customising manufacturing strategy on product design by considering γ_j.

The goal of the push–pull manufacturing strategy is that the manufacturer will minimise the expected on-hand inventory so as to give guaranteed lead times. Furthermore, in terms of supply chain design, it is important to link γ_j to the manufacturing strategy in order to align product design and supply chain as a manifestation of design for the supply chain.

In terms of TC_j effect on the product commonality index, Equation (12) informs us that the higher TC_j reduces π_j and furthermore γ_j. Since angle between ideal product (P) and existing product (Q) grows wider, then, the increasing of TC_j will decrease product commonality γ_j. Reducing TC_j can be accomplished by reducing inbound service time W_i and its standard deviation σ_{m-j} so as to change safety stock level and CODP.

Another result on cost model is that reducing W_j to minimise TC_j can be accomplished by customising push–pull manufacturing strategy in considering facility capability. By assigning safety stock appropriately to each product variant, then it is possible to eliminate some of the holding cost of such a product variant that is assigned to MTO or MTS. Obviously, it should be traded off with service cost C_{T-j}, where shorter W_j results in higher C_{T-j} (see Equation (6)).

An impact of higher product commonality index on cost reduction is that higher product commonality index lowers safety stock by reducing demand standard deviation between product-*j* and product-*k* σ_j. Let us suppose that σ_j^2 is the demand variance of product-*j*, thus if we have two product variants *j* and *k*, then we have demand standard deviation for the two variants as $\sigma_{jk} = \sqrt{\sigma_j^2 + \sigma_k^2 + 2\rho\sigma_j\sigma_k}$ where $\rho\sigma_j\sigma_k$ is the covariance of D_j and D_k. Thus, reducing a product variant's correlation ρ will reduce σ_{jk} where it implies higher product commonality index.

5 Conclusion and future research

This paper has discussed mass personalisation of the customisable product family through product and process reconfiguration, followed by revenue optimisation in considering the material procurement prices. We may summarise the results derived from the model as follows.

1 Manufacturing process design customisation supports product development process optimisation. In fact, this effort is devoted to increasing the product platform commonality by minimising total costs for the entire product family.

2 The inclusion of the customer in the product development process enables the application of design for MC (Jiao and Tseng, 1996). This result supports the conclusion of Tseng and Du (1998), who concluded that customers can make choices and find out their needs. Our paper, however, gives additional advantage by showing

the benefit of customer involvement for manufacturing process design by creating push–pull manufacturing strategy to reduce lead times and total costs.

3 Linking the manufacturing strategy (strategic safety stock allocation and push–pull CODP) and γ_j to increase product platform commonality and total costs are the main outcomes of this paper. This conclusion corresponds with supply chain design by giving an in-depth analysis from the product, process and supply chain point of view (Salvador, Rungtusanatham and Forza, 2002), and finally building an analysis of concurrent engineering by sharing information between the marketing department, PDD and manufacturing process department, as well as suppliers (Sharifi, Ismail and Reid, 2006).

In terms of future research direction, the area of model application should be expanded to supply strategy in order to induce innovation on component platform modularity. Future research should investigate the advantage of this proposed model for knowledge sharing so as to encourage supply chain collaboration.

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APPENDIX E.

PAPER 3.4.7

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Built-to-order supply chain: response analysis with control model

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Abstract: This paper focuses on control systems modelling built-to-order buyers facing customised demand. The general purpose is to present a novel approach to managing collaboration, by considering information exchange between the buyer and the supplier. The methodology applies feedback control mechanism to analyse supplier responsiveness and product platform commonality degree to represent the need for product platform standardisation. A two stage game is applied ahead of control system application to optimise the production rate decision and supply contract, with the ultimate goal being profit maximisation and stabilisation. The results show that a higher product commonality degree gives more opportunity for quick response built-to-order supply chains at minimum shop floor operations changes, which are managed by feedback control. Furthermore, a contribution to collaborative supply chains is shown by applying a synchronised supply model to represent supplier and the buyer communication.

Keywords: collaboration; control system; game theory; simulation; supply chain management.

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1 Introduction

Lead times and inventory level are two strategic decisions which supply chain manager's face over time. Holweg et al. (2005) showed four types of collaboration to increase responsiveness and lower inventory cost. These can be classified according to the level of integration, the capability of integration of the supply chain, geographical dispersion and demand patterns. Christiansen et al. (2007), however, argued against this investigation and showed that only collaborative planning, forecasting and replenishment (CPFR) can be categorised as collaborative effort.

The Holweg or Christiansen definitions of collaboration are difficult to apply directly to global and order based supply chains that are characterised by location diversity, control limitation, uncertainty and complexity. One reason is that global and order-based firms are different from centralised and mass production based ones in many respects. These differences extend to the requirements with respect to agile manufacturing because of consumer preferences for diversification (Gunasekaran et al., 2008). Thus, most previous discussions were focused on information visibility (Holweg et al., 2005), without considering the benefit of product commonality on collaboration.

So far few serious attempts have been made to investigate the effect of product commonality on the dynamics of collaboration instead of its value at any given time (Jiao and Tseng, 2000; Mikkola and Larsen, 2004; Blecker and Abdelkaffi, 2007; Mikkola, 2007). However, the dynamic property is important with regard to making the decentralised supply chain strategic decisions.

In considering the importance of agile manufacturing to responsive supply chains (Gunasekaran et al., 2008), it is essential to take into account the possible effects of product commonality and collaboration for built-to-order (BTO) supply chains. In particular, collaboration according to speed and flexibility by considering supplier-buyer communication, which affects the firm's production quantities as well as inventory level and designing innovative products (Gunasekaran et al., 2008) as a collaboration at the product design phase (Blecker and Friedrich, 2007). Finally, as a result of product platform standardisation, it is important to investigate its benefit to supply chain collaboration.

In addition to recent literature, closed loop second order control analogy is a special case in terms of this collaboration. This approach has been introduced conceptually by Holweg et al. (2005) and this paper translates the concept into control system methods. This model is different to control theory application in management science (Sethi and Thompson, 2000; Sethi, 1977), where the decision is assumed to depend merely on the single firm, without considering other party's reactions. This approach introduces a more realistic and observable method by looking at the dynamic behaviour of the two sides, the buyer and the supplier. Generally speaking, we investigate the control approach on the customised supply chain objective and profit maximisation by finding the optimum production rates (buyer and the supplier) and product commonality degree.

In Section 2 we introduce background for the research on dynamic analysis in competition and the research area of this paper. In the following section, a two stage game is described, in which the buyer and the supplier are analysed using the production and supply contract model while the supply chain collaboration is examined by utilising the response analysis through control model (Section 3). The problem example section presents and discusses the simulation results. The managerial implication section exhibits benefit of the proposed models. The conclusion and further research sections explore the information behind the simulation results in the previous section and discuss some future research opportunities.

2 Background for the research

Dynamic analysis was used to represent a decision maker who intends to plan his capacity in advance according to the present situation (Smithies and Savage, 1940). In contrast, Dudey (1992) argues against the idea by introducing dynamic Edgeworth-Bertrand competition in order to solve dynamic competition under capacity constraint and presenting dynamic pricing, which can be changed at any time. When this game is duopoly, the payoff function of each firm maps the duopolists' strategy choices into the firm's total expected profit. Event though the Dudey model used dynamic pricing, this model does not present dynamic capacity as a result of demand change.

Singh and Vives (1984) focus their analysis on flexible capacity/price appropriateness to hedge against predetermined price/quantity contracts. Their analysis adapts to a new demand or price after making a price or delivery quantity contract formerly under the absence or presence of product substitutability degree. In contrast to that paper, our contribution is focused on a dynamic analysis of the capacity, by considering supply chain responsiveness. The tournament model (Gibbons, 1992) is used to represent a production game to investigate the product variety effect on supply chain performance (Miegham and Dada, 1999; Gustafsson and Norrman, 2001).

The application of dynamic analysis to management science was introduced by Sethi (1977), for instance revenue optimisation in persuasive advertising models. The same principle is also applied in the context of logistics because of its applicability to coordinated supply chains. This paper serves as a fundamental description for future research in supply chain control.

Control application in supply chains is closely linked to an important issue with regard to the properties of industrial dynamics (Forrester, 1958; Houlihan, 1987; Towill, 1996; Christopher and Towill, 2001; Wilkner et al, 2007), which further carries on the bullwhip effect that possibly emerges along value chains. Forrester (1958) applies some tools from electronic data processing to feedback control in order to show how some input factors such as decisions, delay and prediction influence the smoothness of operations. Furthermore, the paper describes the bullwhip effect as the delay in some order processing stages which causes fluctuation behavior. This reminds us of the importance of improving control that can produce faster order handling and better sales data.

By considering BTO control problems from the point of view of the supplier, however, the previous literature does not adequately address the importance of product variety (Jiao and Tseng, 2000; Mikkola and Larsen, 2004; Blecker and Abdelkaffi, 2007) on supply chain performance. Recently, Holweg et al. (2005) have studied the information visibility implications from the supplier's point of view by extending the supplier responsibility up to the buyer sales point, resulting from the existence of information exchange. Previously, the effect of product variety on manufacturing performance has been investigated in terms of quality and productivity (MacDuffie et al., 1996) by suggesting complexity postponement through product and process redesign (Lee, 1996). Recently, Miles and Snow (2007) and Gunasekaran et al. (2008) insisted on collaborative capability to increase innovation capacity. Thus, information transparency supports supply chain performance in terms of manufacturing capability (Christiansen et al., 2007; Si et al., 2009) by putting orientation in a triple-A supply chain of agility, alignment and adaptability (Merminod et al., 2007) so as to link between supply chain performance (manufacturing and financial) and supply chain collaboration in terms of information transparency (Van der Vaart and Van Donk, 2008).

The purpose of this paper is to generalise Holweg's model to address the information visibility issue mentioned above. Demand information visibility is imposed on the model so as to ensure that the demand for an order is fulfilled as much as is needed for supporting electronic procurement (Schoenherr and Tummala, 2007). In addition, the problem of simultaneously solving the optimal ordering and price discount problem for the supplier and buyer is addressed (Hu and Munson, 2007). It is shown that the optimal solution now depends on both the total costs of the supplier and the buyer together with their production rates and product commonality decisions. Holweg's model on synchronised supply naturally becomes a special case of our generalised model so that we propose a feedback control mechanism for BTO supply chains.

3 Model description for supply chain design and control

This section is composed of two subsections, namely supply chain design and response analysis with control model. Supply chain design (Section 3.1) details how to allocate buyer and supplier's production rates to minimise safety stock and response time and at the same to built supply contract for providing guaranteed lead times to customers. Thus, response analysis with control model is used to analyse the optimum response rate (Section 3.2). Each subsection is detailed as follows.

3.1 Supply chain design

Suppose now that two firms (one buyer and one supplier) can agree on only two types of contracts: replenishment contract and production contract. To focus the discussion, this paper uses the two stages game, by considering the buyer as a first mover at stage-j and the supplier as the second mover at stage $j - 1$. To defence of this consideration, it is often in business negotiation that a buyer takes advantage as a first mover by proposing their requirements by considering their own profits and a supplier will take action just after received the buyer request. Thus a supplier needs to optimise their production plan to avoid profit violation. First, we analyse stage 1 to optimise the buyer production rate against the buyer revenue maximisation as Section 3.1.1 and stage 2 to optimise the supplier production rate against the buyer production rate (Section 3.1.2) as below.

3.1.1 Buyer and supplier choose optimal production rate and services time at stage-j and stage j – 1

We solve the buyer optimum production quantity by decomposing the multi-stage supply chain strategic inventory location model into J stages, where J is the number of workstations in the supply chain and there is one stage for each node. For each node-j we define μ_j^* to be the optimum service rates and W_j to be the optimum service times. We use μ_j^* and W_j formulation of Kristianto and Helo (2010) by considering that our production process is high mix and high volume so the demand intensity is non stationary and unstable. Thus we have the following (see Kristianto and Helo, 2010).

$$\mu_j = 2.\lambda_j \pm \frac{\sqrt{2.\left(\sigma_{A-j}^2 + \sigma_j^2\right).\lambda_j.C_{W-j}.C_{T-j}}}{2.C_{T-j}} \tag{1}$$

$$W_j = \frac{\mu_j}{\lambda_j}.W_{q-j} \tag{2}$$

where $W_{q-j} \le \frac{\lambda_j\left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2\left(1-\rho_j\right)}$ is maximum waiting time in a queue according to GI/G/1 queue system, σ_{A-j} and σ_j in equation (1) denote the demand inter-arrival rate standard deviation and service rate standard deviation at stage-*j*. σ_{A-j} can be found as maximum difference between average inter-arrival time $\frac{1}{\lambda_j}$ and maximum inter-arrival time at maximum demand rate during net replenishment time $\frac{1}{\lambda_j + \sigma_{D-j}}$ or $\sigma_{A-j} = \frac{1}{\lambda_j} - \frac{1}{\lambda_j + \sigma_{D-j}}$ where σ_{D-j} is demand rate standard deviation and utilisation factor ρ_j can be found from $\rho_j = \frac{\lambda_j}{\mu_j}$ (see Gross and Harris, 1974). The two results of equation (1) can be used to decide on the buyer optimum production rate by considering the least non-negative μ_j value at stage-*j*. This decision is also applied to supplier production rate μ_{j-1}^* and services time and W_{j-1}. The above models modifies Caldentey and Wein (2003) single server queue model into GI/G/1 model (Kristianto and Helo, 2010) that is used to extend the problem from one buyer and one supplier into multi-stages optimisation by giving 100% guaranteed lead times.

Obviously in real business negotiation, it is important to get trust from partners in order to meet all of objectives (promised lead times and low costs of manufacturing). Thus, below is proposed business negotiation in terms of supply contract between one supplier and one buyer by considering reward and penalty for contract items violation.

3.1.2 Contract strategy between a buyer and a supplier

Suppose in the delivery contract the buyer as a customer takes the initiative by announcing a contract proposal which contains some requirements, for instances delivery promptness and prices, and the buyer and the suppliers' responsibilities. Thus we modify tournament game (Gibbons, 1992) to solve this problem as follows.

Suppose that σ_{ij}^2 is supplier service time variance and σ_{T-j}^2 buyer production process time variance at stage –*j*. Thus, if we assume that between supplier and buyer are independent, then we have the buyer service rate standard deviation as $\sigma_j = \sigma_{(m+p)-j} = \sqrt{\sigma_{ij}^{\,2} + \sigma_{T-j}^{\,2}}$ (Kristianto and Helo, 2010). The buyer will propose incentive I to reducing $\left(\sigma_j - \sigma_j^{\,*}\right)$ where σ_j and $\sigma_j^{\,*}$ are the buyer actual processing rate standard deviation and planned processing rate standard deviation where they depend on the supplier processing rate standard deviation σ_{ij}. Thus, we have the following incentive proposal as below.

Suppose the supplier and the buyer has established a long term contract by choosing the incentive I and penalty cost p for the supplier. The firm gives incentive to the suppliers whenever they can deliver the buyer in the predetermined service time range at $W_i \pm \sigma_{ij}^{*}$. If production accuracy $\left(\sigma_{ij} - \sigma_{ij}^{*}\right)$ is to be a common objective between the supplier and the buyer, then, for each i, σ_{ij}^{*} must maximise the supplier's expected profit, net of penalty and holding costs: $\left(\sigma_{ij}^{*}\right)$ must solve

$$\begin{aligned} &\max_{\varepsilon_t \geq 0} I.\Pr ob\left\{W_i\left(\sigma_{ij}\right) = W_i\left(\sigma_{ij}^{*}\right)\right\} - p.\Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} \\ &-h.\Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} = \left(p-h\right)\Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} \\ &-p+\left(I+p\right)\Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} \end{aligned} \tag{3}$$

The first order condition for (9) is

$$\left(p-h\right)\frac{\partial \Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\}}{\partial \sigma_{ij}} = \left(I+p\right)\Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} \tag{4}$$

That is, the firm and the supplier choose incentive I, penalty p and holding h costs, such that the over or under estimation of variance $\Pr ob\left(\sigma_j - \sigma_j^{*}\right) > 0$ is minimised, which is the probability of over estimation. From Bayes rule,

$$\begin{aligned} \Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} &= \Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} \\ \Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} &= \int_{\varepsilon_t} \Pr ob\left\{W_i > \sigma_{ij}^{*} + \sigma_{ij} - W_i \middle| \sigma_{ij}\right\} f\left(\sigma_{ij}^{*}\right) d\sigma_{ij}^{*} \\ \Pr ob\left\{W_i\left(\sigma_{ij}\right) < W_i\left(\sigma_{ij}^{*}\right)\right\} &= \int_{\varepsilon_t} 1 - F\left(\sigma_{ij}^{*} + \sigma_{ij} - W_i\right) f\left(\sigma_{ij}^{*}\right) d\sigma_{ij}^{*} \end{aligned} \tag{5}$$

So the first-order condition (11) becomes

$$\left(p-h\right)\int_{\sigma_j} f\left(\sigma_{ij}^{*} + \sigma_{ij} - W_i\right) f\left(\sigma_{ij}^{*}\right) d\sigma_{ij}^{*} = \left(I+p\right)\Pr ob\left\{W_i\left(\sigma_{ij}\right) = W_i\left(\sigma_{ij}^{*}\right)\right\}$$

In a steady state (i.e., $W_i^{*} = W_i$), we have

$$\left(p-h\right)\int_{\sigma_j} f\left(\sigma_{ij}\right)^2 d\sigma_{ij} = \left(I+p\right)\Pr ob\left\{W_i\left(\sigma_{ij}\right) = W_i\left(\sigma_{ij}^*\right)\right\} \tag{6}$$

If ε is normally distributed with variance σ^2 for example, then

$$\int_{\varepsilon_t} f\left(\sigma_{ij}\right)^2 d\sigma_{ij} = \frac{1}{2\sigma_{\left(\sigma_{ij}-\sigma_{ij}^*\right)}\sqrt{\pi}} \tag{7}$$

$$\frac{\left(p-h\right)}{2\sigma_{\left(\sigma_{ij}-\sigma_{ij}^*\right)}\sqrt{\pi}\left(I+p\right)} = \Pr ob\left\{W_i\left(\sigma_{ij}\right) = W_i\left(\sigma_{ij}^*\right)\right\} \tag{8}$$

if is $\sigma_{ij}-\sigma_{ij}^*$ assumed to be continuously distributed ($N \to \infty$), then $\sigma_{\sigma_{ij}-\sigma_{ij}^*} = \sqrt{\int\left(\sigma_{ij}-\sigma_{ij}^*\right)^2 p\left(\sigma_{ij}\right)d\sigma_{ij}}$ and equation (8) becomes

$$\frac{\left(p-h\right)^2}{2\sqrt{\pi}\left(I+p\right)^2} = \left(\sigma_{ij}-\sigma_{ij}^*\right) \tag{9}$$

Equation (9) signifies that increasing incentive I and penalty cost p will reduce $\left(\sigma_{ij}-\sigma_{ij}^*\right)$ significantly. We can show that the buyer considers p instead of I because it can reduce $\left(\sigma_j-\sigma_j^*\right)$ more effectively and so is the supplier because one does not like to be threaten. This situation supports previous theory on strategic moves game that threat always trustable in the opponent's point of view. Effects of those strategies will be examined by analysing the supply chains response through control model as Section 3.3 below.

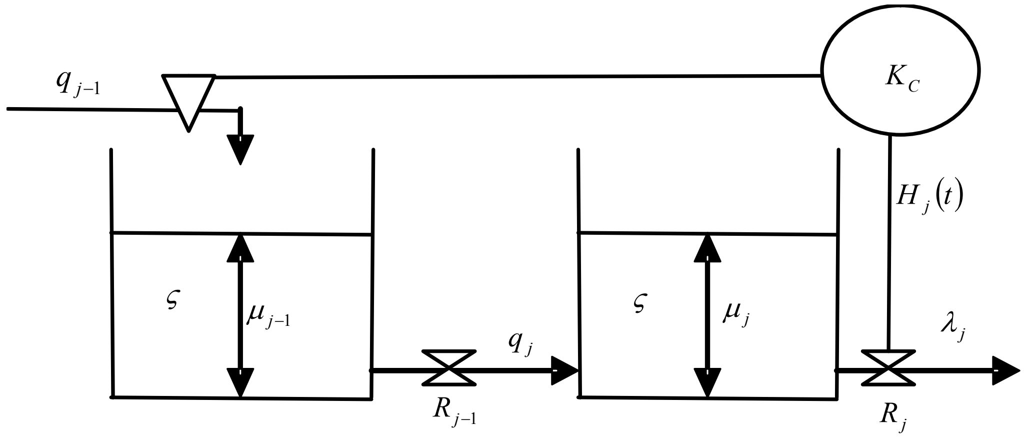
3.3 Response analysis with feedback control model

Difference equations are required to model our continuous control mechanism in order to get a real description of how the ramp up period in the production plant develops. These difference equations can quickly be turned into a mathematical model of feedback control by using Laplace-transforms (Wilkner et al., 2007), which is represented as a two tank interaction as follows.

Figure 1 depicts an interaction between stage $j-1$ and stage-j. This model modifies the Holweg et al. (2005) model (synchronised supply) by replacing the inventory level with production rate at stage-$j\mu_j$. A feedback control mechanism is introduced to represent the interaction as follows.

From this point on our discussion refers to second order fluid dynamics modelling that is adopted in BTO supply chains with an assumption that the supply chain system oscillates due to customer demand variety. The formulation and exploitation of such a mathematical model is not presented in this contribution due to space restrictions but can be found in Luyben (1990).

Figure 1 Supplier buyer collaboration



In defence of a closed loop system with information feedback application, it is often difficult in practice to react against demand change once at a time. A stage-*i* might use incremental production rate by considering stage-*i* and stage-*j* inventory levels and transportation availability. The closed loop control system presented herein is consistent with this perspective.

In stage-*i*, the POS data is bounded so that we have demand rate at stage-*j* at the end of the review period-*t* as $D_j(t)$ (In our example it is taken as 1000 units per week), and is then compared with the average demand rate at stage-*j*. Thus, a new additional production plan and replenishment order to stage-*i* need to be established as $H_j(t) = D_j(t) - \lambda_j$.

It is important to understand that stage-*i* demand is obtained from accumulative of the whole product variants' demands within product family at stage-*j* or $D_{ij}(t) = \sum_{j \neq i} \Phi_{ij}.\lambda_j$ where it is expressed as follow

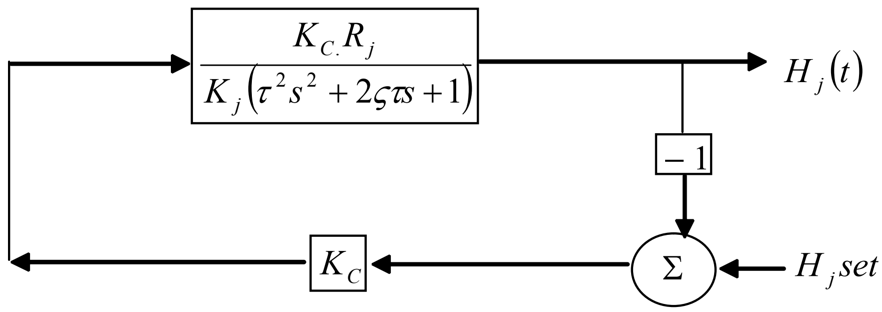
$$\frac{H_j(s)}{\mu_i(s)} = \frac{R_j}{K_j\left(\tau^2 s^2 + 2\varsigma\tau s + 1\right)} \tag{10}$$

$$\frac{\mu_i(s)}{H_j(s)} = K_j = G_j \tag{11}$$

We recognise R_j in (10), which denotes delivery cycles product j, and it equals $\frac{\lambda_j}{q_j}$ where q_j is economic order quantity of product-*j* at certain values of *h* and setup cost s. τ is stage $j-1$ rise time characterising the response to a time-varying demand of stage-*j* and it just equal to stage-*j* processing time $W_j = \frac{\mu_j\left(\sigma_{A-j}^2 + \sigma_j^2\right)}{2\left(1-\rho_j\right)}$. K_j represents utilisation factor ρ_j to inform us whether in our order there is a delay/backorder at stage-*j*, or not. The damping coefficient ς provides a mathematical means of expressing the level of damping in a system and in this paper we use ς value is equal to $\frac{1}{\gamma}$ where γ is product platform commonality degree to signify quickest and most accurate response to customer demand at stage j where the higher value denotes more accurate response. Thus, ς signs supply chain flexibility.

In defense of the relationship $\varsigma = \frac{1}{\gamma}$, it is often that make-to-stock (MTS) production is applied into high mix production system where flexibility is a must. MTS is also signified by higher value of γ to induce higher flexibility. Lower ς represents quicker response to customer demand and on the other hand, higher ς represents slower response to customer demand. Thus, we have closed loop feedback control as,

Figure 2 Closed feedback control transfer function



K_C in Figure 2 represents stage $j-1$ responsiveness. For instance, if the demand change at stage-j is $H_j(t) = 100$ units at the end of review period, then, $K_C = 1$ will change the production rate ±10% of $D(\tau)$. The larger the K_C, the more the production rate will change for a given $H_j(t)$. In defence of K_C application, it is often difficult in practice to assess responsiveness for an external customer. Similarly, when we asked managers for their desired responsiveness, more often than not the response is that there should be no stock outs for external customers (Graves and Willems, 2000). Thus, K_C gives reaction in proportion to the error $H_j(t)$ so that the production facility reduces or increases gradually the target point with very little, if any, 'safety stock level overshoot' so that the result is a smooth inventory level. This implies that higher K_C requires more frequent changes in shop floor operations as is compared to lower K_C. Finally, Figure 2 can be used to find its open loop transfer function, as follows,

$$\frac{\mu_{j-1}(s)}{\lambda_j(s)^{set}} = \frac{K_C \dfrac{R_j}{K_j\left(\tau^2 s^2 + 2\varsigma\tau s + 1\right)}}{1 + K_j \dfrac{R_j}{K_j\left(\tau^2 s^2 + 2\varsigma\tau s + 1\right)}} = \frac{K_C.R_j}{K_C.R_j + K_j\left(\tau^2 s^2 + 2\varsigma\tau s + 1\right)} \qquad (20)$$

So we have roots of denominator as

$$s_{1,2} = \frac{-\left(\frac{2\varsigma\tau K_j}{K_j\tau^2}\right) \pm \sqrt{\left(\frac{2\varsigma\tau K_j}{K_j\tau^2}\right)^2 - 4\frac{K_j + K_C.R_j}{K_j\tau^2}}}{2}$$

Laplace domain dynamics according to step disturbance is applied in order to represent sudden demand change, which can be inserted directly into (20) and inverted to obtain the following inversion of the Laplace transform, as follows

$$\frac{\mu_{j-1}(s)}{\lambda_j(s)^{set}} = \frac{1}{s(s+a)(s+b)} \tag{21}$$

where

$$a = \frac{\left(\frac{2\varsigma}{\tau}\right) + \sqrt{\left(\frac{2\varsigma}{\tau}\right)^2 - 4\frac{K_j + K_C.R_j}{K_j\tau^2}}}{2}$$

$$b = \frac{\left(\frac{2\varsigma}{\tau}\right) - \sqrt{\left(\frac{2\varsigma}{\tau}\right)^2 - 4\frac{K_j + K_C.R_j}{K_j\tau^2}}}{2}$$

Finally, a time domain dynamics of synchronised supply can be formulated as follows

$$\mu_{j-1}(t) = \left(1 - \frac{e^{-at} - e^{-bt}}{(b-a)}\right)\lambda_j(t)^{set} \tag{22}$$

Equation (22) concludes our process modelling in closed loop feedback control by defining optimum parameter K_C and ς that can be determined by using Ziegler-Nichols (ZN) controller settings (Luyben, 1990). The ZN method consists of first finding the ultimate gain K_U, the value at which the loop is at the limit of stability with a proportional only feedback controller. Thus, optimum K_C can be calculated from K_U as $K_C = 0,5.K_U$.

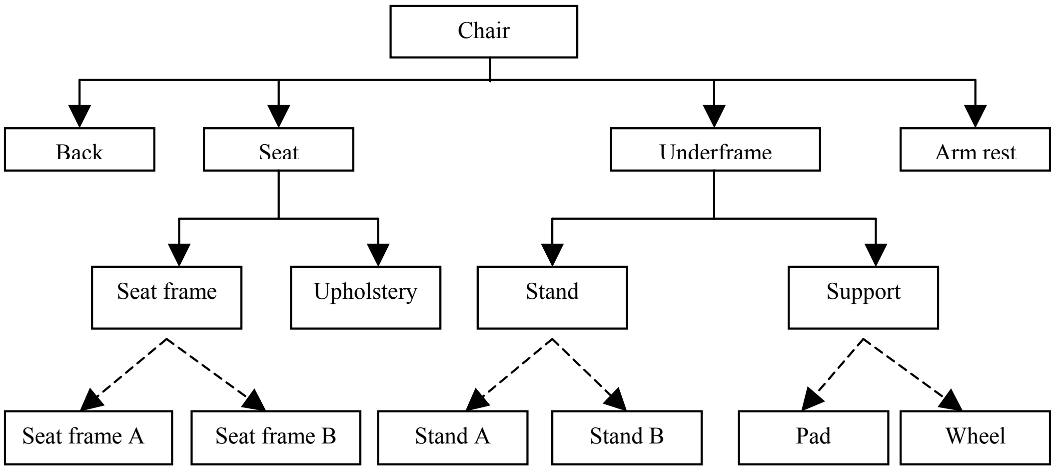
4 The problem

Section 4 is introduced to demonstrate the operability of the proposed models. This Section is divided into two sub sections where Section 4.1 exhibits the situation of the problem example and Section 4.2 discussed the results and explores some information behind the results.

4.1 Illustrative example

Our example is the supply chain design for a product family of office chair (see Kristianto and Helo, 2010). The underframe is composed of two modules – the stand and the support. The seat is composed of the upholstery and the seat-frame. The Customers are allowed to select whether or not a chair is turnable, drivable and whether or not it has armrests. The example seemingly looks very simple to be used to demonstrate our models.

Figure 3 General product structure



Source: rewritten from Kristianto and Helo (2010)

In focusing our discussion, we use the results of product platform commonality degree γ formulation of Kristianto and Helo (2010). In presenting synchronised supply and K_J is obtained from our supply chain design Section by finding stage-j (the buyer) utilisation factor.

First, the buyer transmits point of sales (POS) data λ_j to the supplier's factory in monthly basis. This information is then compared with the inventory of available components. Thus, a new production plan and replenishment order to the supplier both need to be established: for example, how many additional production quantity H_j and ordered component H_{j-1}. The higher H_j and H_{j-1}, the higher component inventory level is required because each component has its own demand variance and safety stock (Lee, 1996). Thus, higher component commonality will reduce inventory level.

Utilising the buyer's POS data (see Table 1 below). Thus, on time delivery can be achieved by pursuing the required production rates μ_i^{set} as soon as possible at predefined K_C and K_j. μ_j^{set} ensures adequate availability without building up excessive stocks [equation (9)].

4.2 Results and analysis

The first step in solving the problem is that calculating how much optimum production rates of the buyer and the suppliers. We extract some data from Kristianto and Helo (2010) as Table 1 below and change some of their values, for instance processing rates standard deviation σ_j now is an independent variable to investigate the effect of supply contract to supply chains response.

Table 1 Manufacturing performances for office chair product family

Stage (J)	*Component/product*	*Independent variables*				
		λ_j	σ_j	σ_{D-j}	C_{W-j}	C_{T-j}
12	Product ABDEGI	300	0.03	30.0	10	15
12	Product ABDEGI	250	0.03	25.0	10	15
12	Product ABDEGI	400	0.03	40.0	10	15
12	Product ABDEGI	300	0.03	30.0	10	15
12	Product ABDEGI	300	0.03	30.0	10	15
12	Product ABDEGI	200	0.03	20.0	10	15
12	Product ABDEGI	500	0.03	50.0	10	15
12	Product ABDEGI	800	0.03	80.0	10	15
11	Back	3050	0.03	305.0	10	15
10	Seat	3050	0.03	305.0	10	15
9	Underframe	3050	0.03	305.0	10	15
8	Seat frame A	1250	0.03	125.0	10	15
7	Seat frame B	1800	0.03	180.0	10	15
6	Upholstery	3050	0.03	305.0	10	15
5	Stand A	1050	0.03	105.0	10	15
4	Stand B	2000	0.03	200.0	10	15
3	Pad	1500	0.03	150.0	10	15
2	Wheel	1550	0.03	155.0	10	15
1	Armrest	3050	0.03	305.0	10	15
Stage (J)	*Component/product*	*Dependent variables*				
		W_i	W_j	W_{q-j}	σ_{A-j}	μ_j
12	Product ABDEGI	4.0	0.5	0.3	0.00030	600
12	Product ABDEGI	4.0	0.5	0.2	0.00036	500
12	Product ABDEGI	4.0	0.7	0.4	0.00023	800
12	Product ABDEGI	4.0	0.5	0.3	0.00030	600
12	Product ABDEGI	4.0	0.5	0.3	0.00030	600
12	Product ABDEGI	4.0	0.4	0.2	0.00045	400
12	Product ABDEGI	4.0	0.9	0.4	0.00018	1000
12	Product ABDEGI	4.0	1.4	0.7	0.00011	1600
11	Back	2.0	4.0	2.0	0.00003	6101
10	Seat	2.0	4.0	2.0	0.00003	6101
9	Underframe	2.0	4.0	2.0	0.00003	6101
8	Seat frame A	2.0	2.3	1.1	0.00007	2501
7	Seat frame B	2.0	3.2	1.6	0.00005	3601
6	Upholstery	2.0	4.0	2.0	0.00003	6101
5	Stand A	2.0	1.9	0.9	0.00009	2101
4	Stand B	2.0	3.6	1.8	0.00005	4001
3	Pad	2.0	2.7	1.3	0.00006	3001
2	Wheel	2.0	2.8	1.4	0.00006	3101
1	Armrest	2.0	4.0	2.0	0.00003	6101

Without loosing generality, our analysis is only subjected to product ABDEGI in Table 1 by considering that all of product variants are developed by using the same way. Thus, the results variation only depends on order size where processing time positively follow order size pattern.

The system responses are measured at different component commonality (γ = 0 implies that each component's variant is non-interchangeable and the component becomes fully flexible when γ approaches unity) and different level of processing times standard deviation are then used to investigate supply chain performance (Gustafsson and Norrman, 2001).

Hence, the results can be illustrated as follows:

Figure 4 Responses analysis at different product platform commonality levels for product variety ABDEGI (see online version for colours)

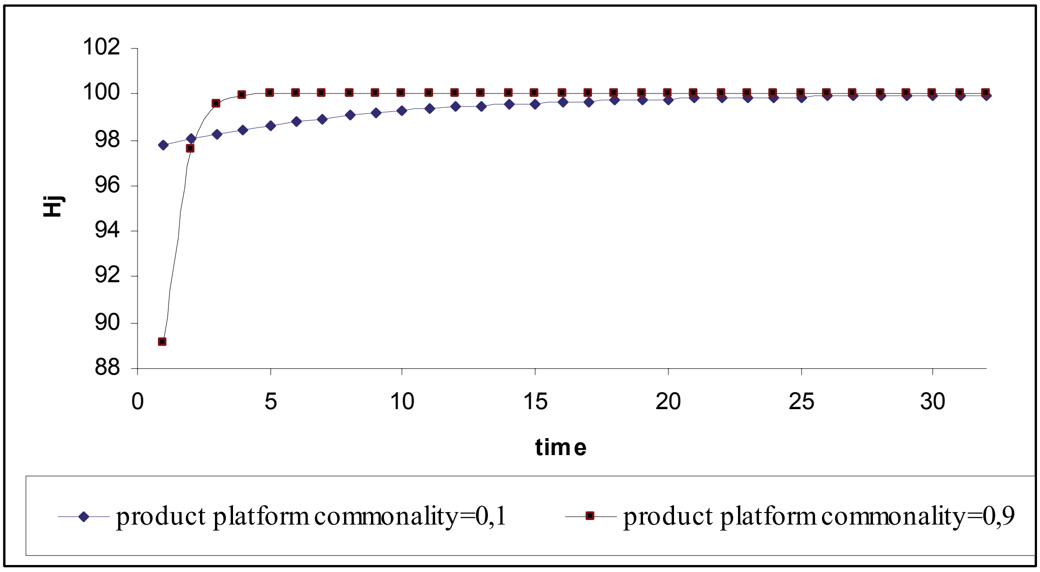


Figure 4 depicts how different commonality strategies benefit the reduction of lead times at the same level of production rates. Specifically, such benefit for the supplier and the buyer goes to those who can increase the product commonality. This result implies that at a higher commonality level, either the buyer or the supplier has lower effect on the services time standard deviation (Figure 5) because the buyer can react faster because of high flexibility on their product platform

Furthermore, the benefit of higher product platform commonality is shown by supply chains production rates stability against demand change by lowering K_C as Figure 6 below.

Figure 5 Responses analysis at different W_j as a result of different σ_j for product variety ABDEGI (see online version for colours)

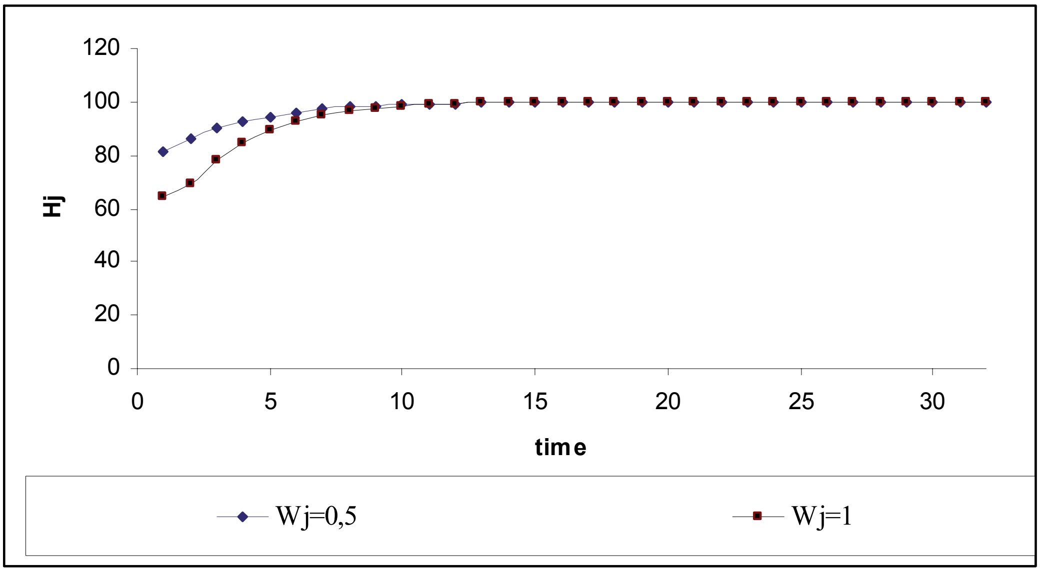
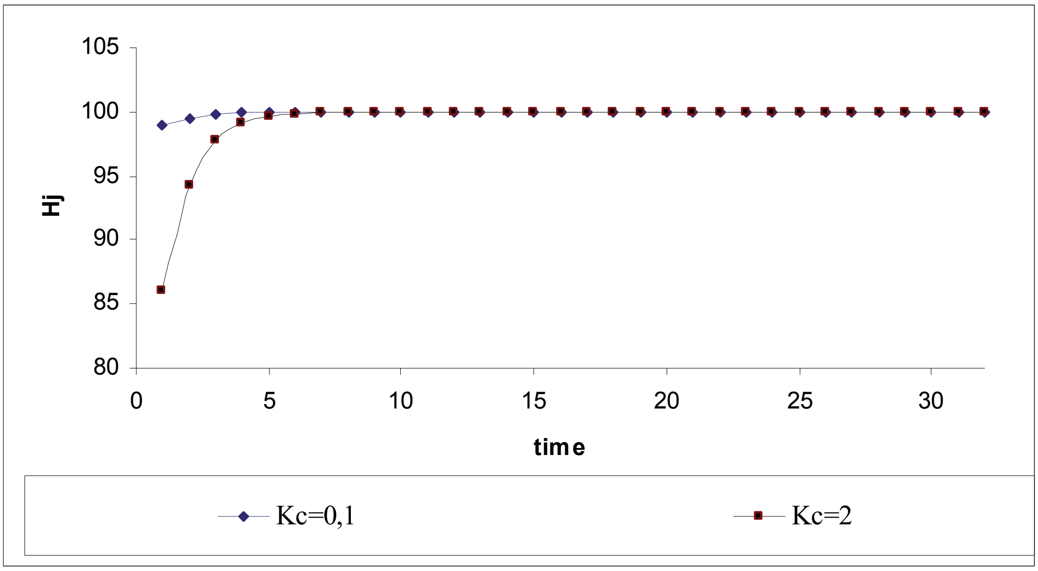
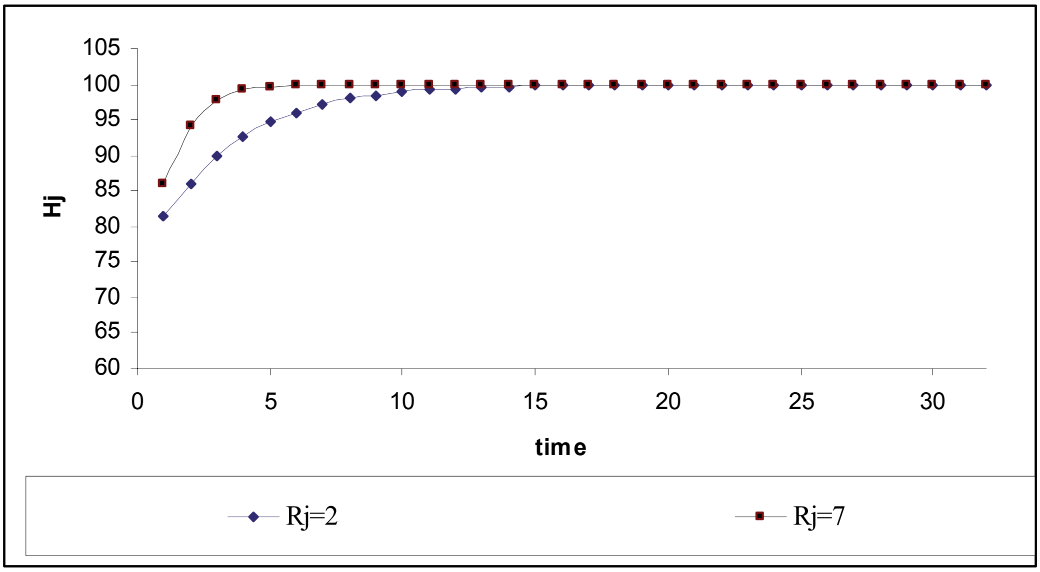


Figure 6 Responses analysis at different K_C as a result of different γ for product variety ABDEGI (see online version for colours)



In considering service time standard deviation σ_j, however, σ_j needs to be minimised by making supply contract (see Section 3.1.2) to minimise h where it takes effect to minimise economic order quantity q_j and minimise lead times (see Figure 7) as follows.

Figure 7 Responses analysis at different R_j as a result of different σ_j for product variety ABDEGI (the higher σ_j, the lower R_j) (see online version for colours)



The effect of supply contract to reducing $\sigma_{ij} - \sigma_{ij}^{*}$ can be exhibited as Figure 8 below by applying equation (9) at various h and I values.

Figure 8 Incentive and penalty costs settings at different preferred delivery promptness violation $(\sigma_{ij} - \sigma_{ij}^{*})$ for product variety ABDEGI

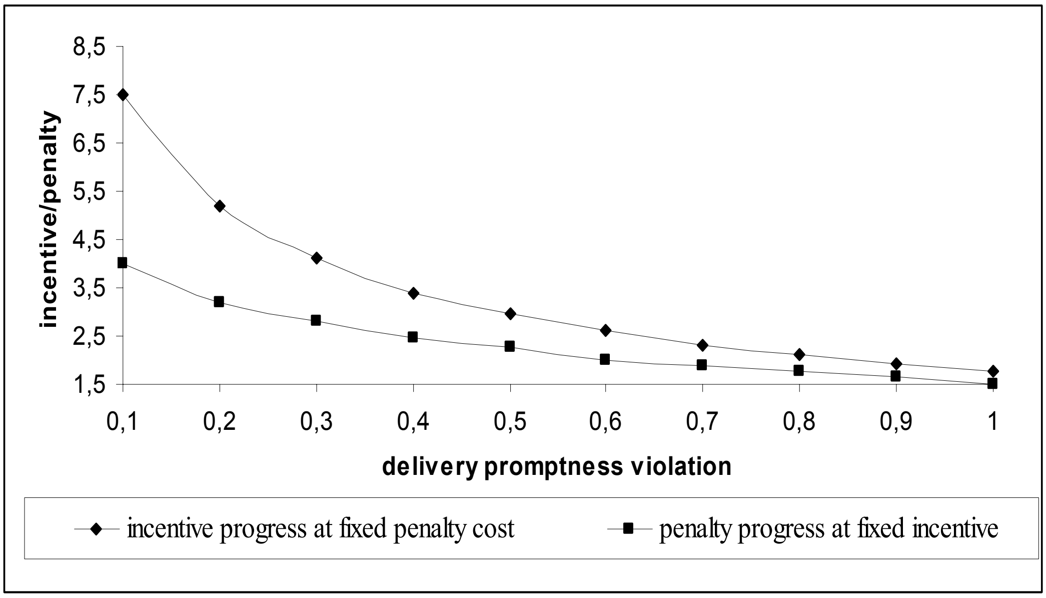


Figure 8 shows that penalty costs is more effective to reducing $\sigma_{ij} - \sigma_{ij}^*$ than supplier's incentive. This result proofs that in real business negotiation, threat is more effective than promise. Otherwise we can combine the both of incentive and penalty together to get better results in reducing $\sigma_{ij} - \sigma_{ij}^*$.

5 Managerial implication

From this discussion, the product manager can take advantage of the proposed model by presenting the mutual impact between the buyer and supplier production quantity decision and product platform development. In this section, we analyse the results and some of the main implications regarding the impacts of platforming strategy on the benefit of production control.

First, higher product commonality benefits the reduction of lead times. Specifically, such benefit comes from the economic order quantity q_j reduction (see Figure 5) on supply chains responsiveness improvement. Furthermore, the benefit of product commonality is shown by the increasing of production rates stability at lower K_C and reducing of Rj significantly at higher commonality degree (Figure 5 and 6), where it can also encourage the supplier to trust POS data. On the contrary, higher K_C (see Figure 6) hinders suppliers in making a quick response since they must spend a certain time in increasing their production rates where in shop floor application it must incorporate production, maintenance, logistics and transportation coordination. Thus, the implication of higher K_C is that all of manufacturing stages must ready for frequent changes against customer demands change where it can be minimised at lower K_C.

Second, higher component commonality is better applied to ATO production systems since it generates lower service time standard deviation σ_j (see Figure 5), thus increasing the supply chain flexibility. Lower value, however, is better applied to MTO since it responds over a longer period, with high responsiveness at higher K_C, by putting emphasis on lower product platform commonality.

This paper implies three main conclusions for managers. First, the feedback control system proposes a real description of how the ramp up period in the production plant develops, as well as investigating the component commonality effect on it. Second, component commonality increases inventory turnover by minimising economic order quantity q_j and safety stock as a result of higher order cycle (Figure 7). The third contribution is that the paper offers a different view of optimal control applications on supply chain collaboration (Holweg et al., 2005).This paper, however, without arguing for either idea, proposes a parameter ς, which denotes flexibility. In general higher ς indicates that the buyer is operating under MTO, while lower ς signs ATO.

6 Conclusion and future research

This paper discusses response analysis of BTO supply chains, which is followed by collaborative decision-making according to single sourcing. We may summarise the results derived from the model, as follows.

1 Product commonality is in linear proportion to response time. Higher commonality takes effect from increasing the service level. This situation is caused by reducing the service time standard deviation σ_j^2 (Lee, 1996).

2 The dynamic behaviour analysis in this paper helps decision makers to decide on their production rates and inventory turnover, by optimising them against the required order cycle. This paper suggests that supply chains should trade-off their production rate decisions according to their customer order response time requirements in predetermined supply contracts (supplier responsiveness K_C and flexibility ς).

3 Linking the decision on production rate, supply contract and BTO control system is the main outcome of this paper. This conclusion complements the previous conclusions of Holweg et al. (2005) by providing in-depth analysis from the control theory point of view. Furthermore, supply contract is added in this model in order to induce supply commitment so as to achieve the required response level.

The analytical model here focused on symmetrical information sharing between two parties. In terms of future research direction, it would be necessary to investigate the possibility of applying strategic thinking in the model, where the supplier assumes that the buyer is not the dominant customer. Thus, it is difficult to maintain information security in terms of the buyer's platform design, so that the issue of security can also be raised. This is a future research area that should be investigated.

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APPENDIX F.

PAPER 3.4.8

Chapter 7

Value Chain Re-Engineering by the Application of Advanced Planning and Scheduling

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The general purpose of the chapter is to present a novel approach to value chain re-engineering by utilizing the new concept of Advanced Planning and Scheduling (APS). The methodology applies collaboration among suppliers, buyers, and the customers to fulfill orders. The models show that it is possible to re-engineer the value chain by incorporating the supply side (suppliers) and demand side (customers) within the new concept of APS. A problem example is given to show how to implement this concept by emphasizing important aspects of supplier and customer relationship. This concept, however, does not take account of the importance of service and customer interface and transport optimization; hence the customer requirement effect cannot be measured. In terms of managerial implication, this chapter maintains that the value chain should incorporate procurement and product development into the main value chain activities since both the activities are more actively in communication with customers. The innovation of this chapter is in including product commonality and response analysis in the simulation model.

Keywords: Value Chain, Advanced Planning, Supply Chain Management, Scheduling, Managerial Flexibility, Market Share

1. Introduction

Meeting customer requirements by customizing the manufacturing strategy is one of the strategic goals which challenge supply chain managers over time. The need for customization has been replacing the current trend of manufacturing in industry which has been continuing since the 1990s where mass production has been shifting to mass customization by featuring the competitive landscape at for instances process re-engineering and differentiation, which forces the manufacturer to be more flexible and quicker response (Pine, 1993). However, this trend has been slowly adopted by up to 60% of the research articles that were published just after 2001–2003 (Du *et al.*, 2003). There have been about 60.000 hits during this period. Furthermore, the current trend of mass customization is shown by the emerging of the personalization concept instead of customization (Kumar, 2008; Vesanen, 2007). The most recent authors mentioned that nowadays the firm needs to be different not only in manufacturing but also in marketing by satisfying the cumulative requirement of price, quality, flexibility and agility at affordable price, by applying information and operational technologies. This trend, however, forces the firm to re-engineer its value chain in order to meet the requirement.

Pine (1993) proposed four types of value chain re-engineering based on customization stages differentiation. In general, the differentiation is categorized according to product and service standardization or customization. A higher customization degree in the value chain processes leads to quick response manufacturing. The idea, however, followed Porter's value chain concept without making breakthrough with the new phenomena of mass customization. Originating from this idea, this chapter applies advanced planning and scheduling (APS) to customize the value chain from back end (supply) to front end (demand).

1.1. *Value Chains and APS*

The value chain as a chain of activities gives the products more added value than the sum of added values of all activities (see Fig. 1) (Porter, 1985). It is important to maximize value creation by incorporating some support activities: for instances, technology development and procurement. Added value is created by exploiting the upstream and downstream information flowing along the value chains, and firms may try to bypass the information to an automated decision maker to create improvements in its value system.

Related to value chain re-engineering, this chapter develops a new model of value chain by referring to the hierarchical planning tasks of APS. The reason behind this decision is that between the Michael Porter value chain and strategic

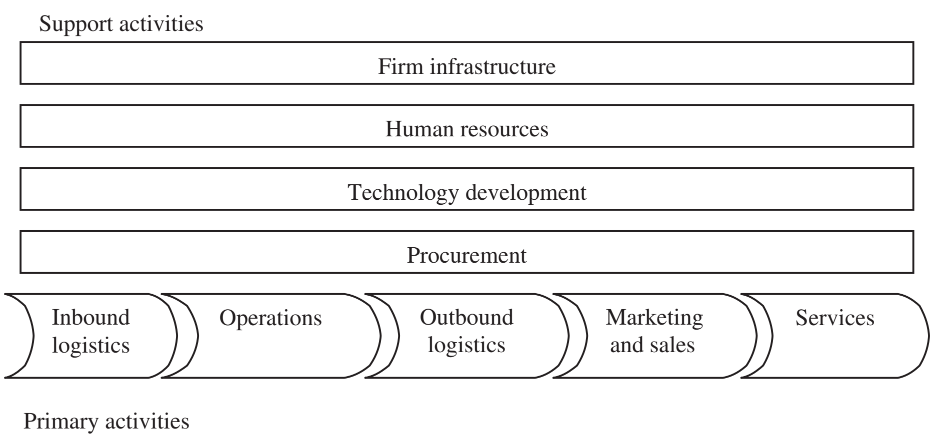

Figure 1. Michael Porter value chain model.

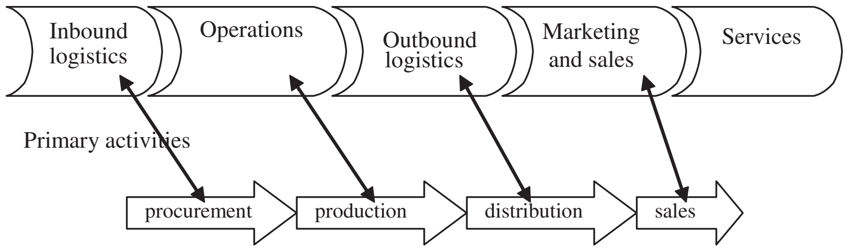

Figure 2. Michael Porter value chain model and APS decision flow.

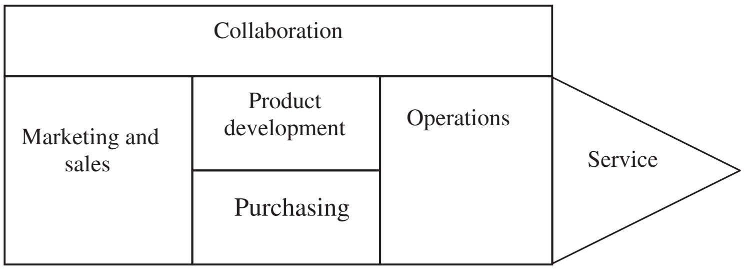

Figure 3. Proposed value chain model.

network planning of APS model is the same vision of creating added value across order fulfillment processes. The relationship can be described in Fig. 2 given below.

From the relationship, this chapter studies a new model of value chain, as follows.

Figure 3 depicts the new concept of value chain, starting from marketing and sales to product development and procurement. New product development receives information from marketing and at the same time back-end operations (purchasing department) coordinate the operations and suppliers simultaneously to fulfill customer demands by optimizing capacity. This model spreads customer information directly to two different sides, the external relation (the suppliers) and internal relation (the manufacturer). This model applies collaboration to improve the customer value by using dynamic material planning. Different from the traditional approach, this model collaborates in every product fulfillment process to synchronize the supply and production capability on a real time basis, according equal benefit of the manufacturer and the supplier. This value chain is then continued to distribution and transport planning, which optimize the entire supply chain by choosing the best distribution channels and transportation.

Related to the APS, Fleischman (2002) describes the hierarchical planning task (see Fig. 4), which, at a glance, figures out the application of value chains from the strategic to the short-term level. The details are represented in Fig. 5 by incorporating the support and the primary value chain activities as follows:

Figure 4 describes task deployment from strategic (long-term planning) to operations (short term), which is detailed further by developing the structure of the

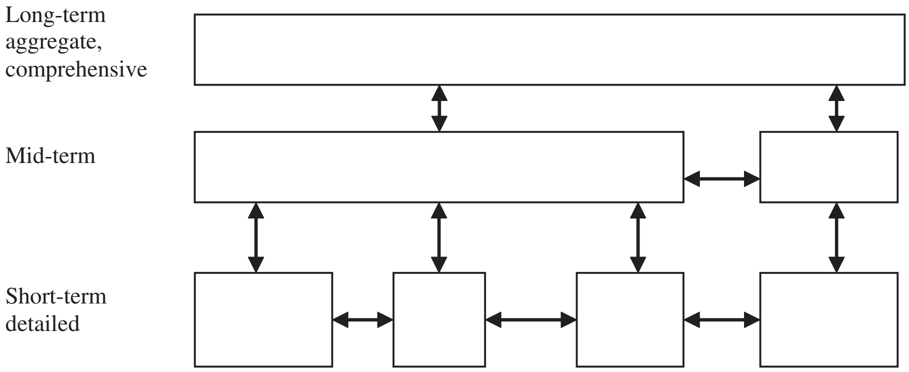

Figure 4. Hierarchy of planning tasks (from Fleischman *et al.*, 2002).

hierarchical planning tasks from Supply Chain Planning Matrix (Stadtler, 2005). The authors propose the two collaboration interfaces of customers and suppliers, as depicted in Fig. 5 below:

Related to the mass customization issue, this situation supports supply chains to be more flexible by assessing each function core competence within supply chains and finding the possibility to develop strategic sourcing instead of in-house manufacturing. In this chapter, we propose an APS methodology to create a link between internal and external operational planning within supply chains to possibly the collaboration between APS (Fig. 5). Unfortunately, this opportunity is less supported by the previous APS function since as it is characterized as follows:

1. In practice, APS is usually concentrated on managing production planning and scheduling by using sophisticated algorithms. Figure 5, however, ignores the

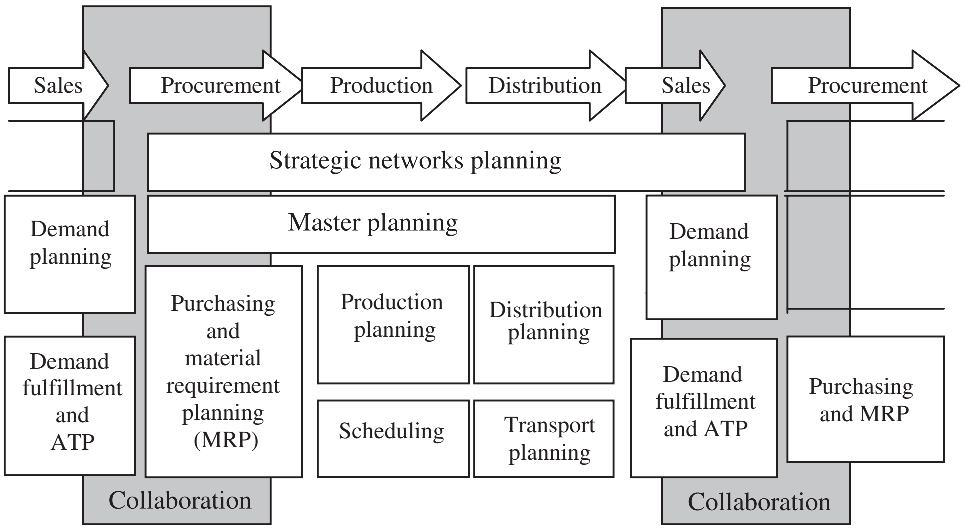

Figure 5. Collaboration between APS (from Meyr, 2002).

collaboration between supplier's available-to-promise (ATP) and buyer's Material Requirement Planning (MRP) by assuming that supplier has infinite production capacity, assumes that lead times are fixed and ignoring the production schedule and sequence (Chen and Ji, 2007).

2. In addition to MRP and scheduling synchronization, APS does not emerge the possibility to activity outsourcing and manufacturing strategy customization, this chapter proposes optimized push-pull manufacturing strategy as well as sourcing strategy optimization. The advantages of this approach are that the manufacturer can reduce the production traffic by outsourcing some activities as well as promising the delivery promptness by using promised lead times in ATP module and making collaborative material planning where the supplier and buyer production schedule are synchronized according to production capacity.
3. Integration with Agile Supply Demand Network (ASDN) adds benefit to this APS model by its ability to reconfigure the supply chain network and to measure the value of the order by financial analysis.

Figure 6 represents the APS scheme to show the difference between new and existing APS.

This new APS model is developed to represent value chain re-engineering. Concurrent engineering is shown by customer and supplier involvement in the process. R&D is included in purchasing and customer involvement is included in order to describe supplier responsibility for product design and at the same time MRP is excluded from the model to represent dynamic material planning. As a replacement, we use collaborative material planning in order to emphasize supply synchronization.

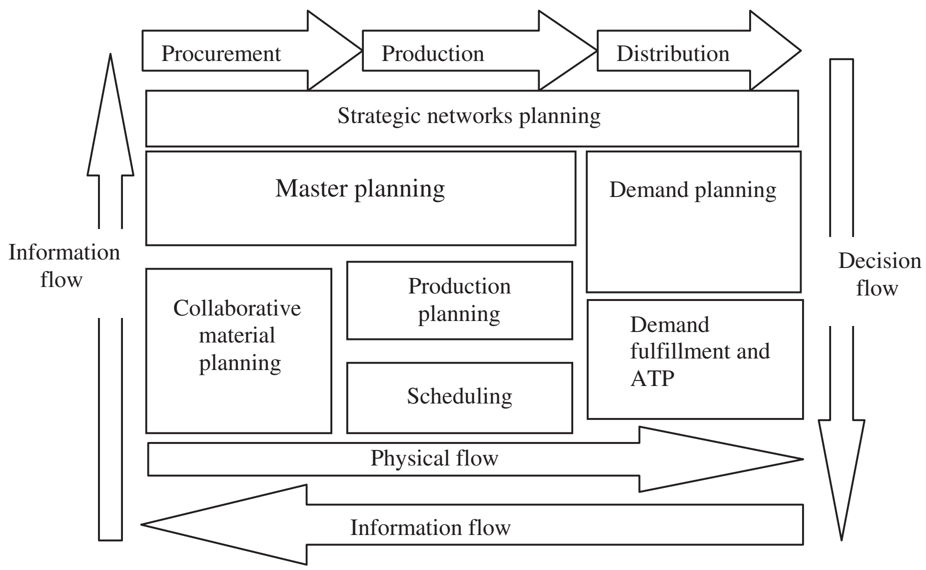

Figure 6. Proposed APS model.

Instead of this new approach, this chapter is composed according to the logic of common APS. First there is a discussion of APS, an introduction at a glance (Section 1.2). From internal coordination, demand planning is discussed in Section 2.1, which informs master planning (Section 2.2) to enable ATP (Section 2.3) by fulfilling the promised lead time (Section 4.3.1) as well as inventory level (Section 4.3.2) and optimizing production sequence and schedule (Section 4.4). From external coordination, material planning (Section 4.5) and network planning (Section 4.6) are also optimized. Moreover, APS is able to optimize supply strategy (Section 4.2.2) as well as the product development process (Section 4.2.4). The key feature of this APS is on profit optimization for the entire supply chain by making a simulation through ASDN software (Section 4.6).

1.2. *APS*

Advanced Planning and Scheduling (APS) could be defined as a system and methodology in which decision making, such as planning and scheduling for industries, is federated and synchronized between different divisions within or between enterprises in order to achieve total and autonomous optimization. Unlike other available systems, APS simultaneously plans and schedules production based on available resources and capability. This usually provides a more realistic production plan (Chen and Ji, 2007).

APS is generally applied where one or more of the following conditions are satisfied:

- Make to order manufacturing instead of make to stock
- The products require a large number of components or tasks to be manufactured
- A capital intensive manufacturing process where capacity is limited
- Products competing with each other to avail the resources
- Unstable situations for resource scheduling that can not be planned beforehand
- It requires a flexible manufacturing approach

Advanced Planning and Scheduling (APS) improves the integration of materials and capacity planning by using constraint-based planning and optimization (Chen, 2007; Marjolein van Eck 2003). There are some possibilities to include suppliers and customers in the planning procedure and thereby optimize a whole supply chain on a real-time basis. APS utilizes planning and scheduling techniques that consider a wide range of constraints to produce an optimized plan (Marjolein van Eck, 2003, for example):

- Material availability
- Machine and labor capacity
- Customer service level requirements (due dates)
- Inventory safety stock levels

- Cost
- Distribution requirements
- Sequencing for set-up efficiency

Furthermore, in the area of supply chain planning, there has been a trend to embed sophisticated optimization logic into APS that helps to improve the decisions of supply chain planners. If it is used successfully, it is not only the supporting of supply chain strategy, but also improves the competitiveness of a firm significantly. Some areas of possible improvement are listed below (Stadtler, 2002):

- Competitiveness improvement
- Make the process more transparent
- Improve supply chain flexibility
- Reveal system constraints

Furthermore, Fleischman *et al.* (2002) mention three main characteristics of APS, which are:

1. Integral and comprehensive planning of the entire supply chain from supplier to end customer.
2. True optimization by properly defining alternatives, objectives, and constraints.
3. A hierarchical planning system from top to bottom that requires cooperation among various tasks in the entire supply chain.

2. Architecture of Proposed APS

With regard to the needs for personalization in the whole value chain, this chapter tries to fill the gap between the requirement and the existing APS by looking forward to finding some benefits as follows:

1. Within value chain building, the most important thing is how to maximize value to customers. This report supports the requirement by proposing reconfigurable push-pull manufacturing strategy. This strategy can adapt to Bill-of-Materials (BOM) changes by reconfiguring the push-pull manufacturing strategy (front side). In order to support the strategy, this APS also optimizes the product commonality to minimize the inventory level as well as production lead times (back side).
2. Within e-customization, the customer meets directly with the manufacturer. The issue which appears is how to minimize customer losses (time and options) and at the same time manufacturer losses (overhead costs, for instance extra administration cost, order cost, etc.). This APS model can minimize both burdens by offering optimum design platform to the customer and the suppliers and a reasonable inventory allocation by push-pull manufacturing strategy (Fig. 7).

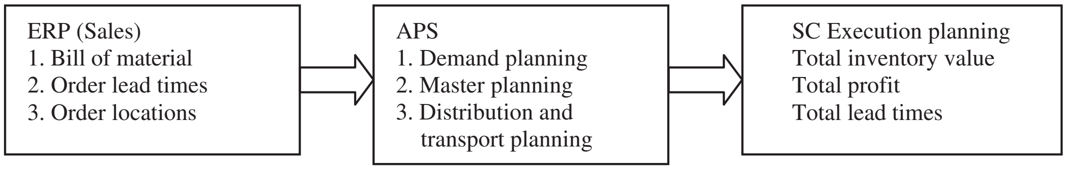

Figure 7. APS model connection to ERP and SC Execution Planning (SCEP).

With regard to the integration issue, this APS module can be composed as follows:

The details of the architecture are elaborated as follows:

2.1. *Demand Planning*

Before going ahead with any production planning process, it is important to calculate the level of demand within a company. Wagner (2002) explored the three main parts of demand planning, namely forecasting, what-if-analysis, and safety stock calculation. The purpose of forecasting is to produce a future prediction related to future demands. What-if-analysis is used as a risk management tool to determine the safety stock level. This ensures the company's proper utilization of space and minimizing the costly inventory level. It also brings integrity to the company's supply chain and logistics network. Demand planning necessitates forecasting and what-if analysis is conducted to make the optimal calculation of required inventory and safety stock level. This chapter, however, comprises an order-based APS where forecasting is only conducted within the push manufacturing strategy.

2.2. *Master Planning*

Master planning is used to balance supply and demand by synchronizing the flow of materials within the supply chain (Meyr *et al.*, 2002). Capacity decision from demand planning will be used to setup product and material price, manufacturing strategy by considering lead times and inventory availability from ATP and possible suppliers' capability from collaborative material planning. Furthermore, master planning is also supported by receiving production schedule information from production planning and scheduling module (see Fig. 8).

2.3. *ATP*

ATP is used to guarantee that customer orders are fulfilled on time and in certain cases, even faster. The logic is shown in Fig. 9 below:

Figure 9 shows three customers who want different requirement and are situated at different locations. ATP optimizes the resources assignments such as materials, semi-finished goods (sub-assembly), and production capacity to guarantee that all

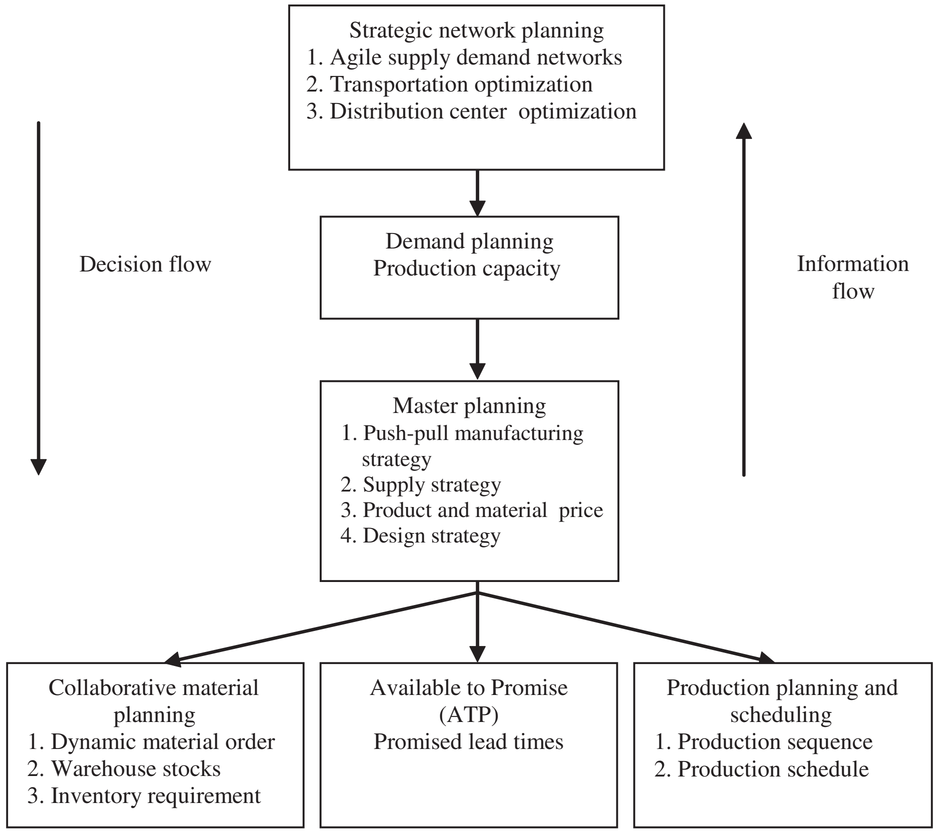

Figure 8. Decision and information sequence within APS.

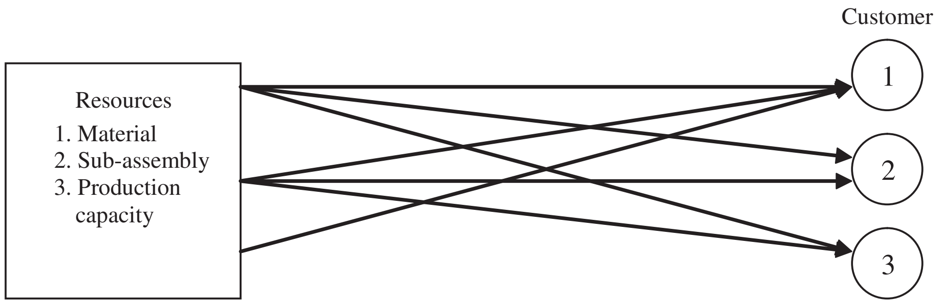

Figure 9. Available-to-Promise.

orders are fulfilled on time. Furthermore, the model is also constrained by inventory level, order batch size, supplier capability, and set-up cost constraints.

Those search dimensions are applied one by one in order to fulfill the customer request. It is easy to observe that the above model emphasizes an iterative approach to solve the ATP problem. The ATP problem, however, goes far beyond the idea. The promise, however, must be fulfilled by the supplier, the manufacturer, and the distributors. This idea supports ASDN by moving the previous APS paradigm from enterprise APS into the supply chain APS (see Fig. 6).

Related to this idea, this chapter, however, shifts some tasks of ATP to master planning by customizing the push-pull manufacturing strategy for each product type and assessing the supply strategy according to sourcing options. Thus, ATP module functions are limited to inventory level and lead times optimization. The impact of this stage can be explained in two ways. First, the global decision within supply chains is more represented by responsibility on all sides (the distributors, manufacturers, and suppliers) so that resources assignment are also possible to be developed across supply chains. Second, it is easier to expand the supply network planning in the future by partially adding new members within the supply chains. This is reasonable since, for example, if the demand continuously increases in the future so that one component needs to be supplied by more than two suppliers, then the APS can collaborate with them.

2.4. *Production Planning and Scheduling*

This module is intended for short-term planning within APS so that it sequences the production activities in order to minimize production time. In detail, Stadtler (2002b) describes a model for a production schedule as in Fig. 10.

Figure 10 depicts the production schedule model building, where it extracts daily operational information in the ERP such as locations, parts, bills-of-material (BOM), production routing, supplier information, set-up matrices and timetables

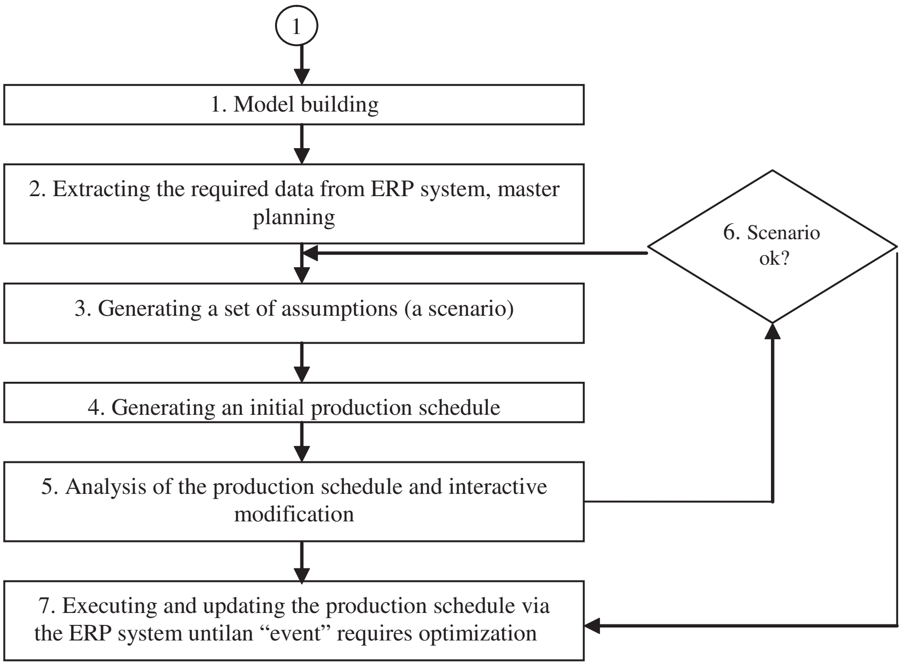

Figure 10. Production planning and scheduling procedure (from Fleischmann, 2002).

(Stadtler, 2002b). This chapter applies the similar optimized scheduling to the entire products by using Traveling Salesperson Problem (TSP) algorithm.

2.5. *Collaborative Material Planning*

In contrast to the traditional approach of operation management tools, where material requirement follows a top-down hierarchical approach, and starts with Master Production Schedule (MPS), the schedule is then detailed into Material Requirement Planning (MRP) by ignoring capacity constraint and assuming fixed lead times. This chapter, however, replaces the MPS and MRP functions by applying collaborative material planning (see Fig. 6) consisting of supplier and buyer integration by including a system dynamics approach (see Fig. 8) by following supply synchronization model and replacing the MRP with collaborative material planning (Holweg *et al.*, 2005) . It is interesting that the model incorporates purchasing and product development, which is useful to give information to master planning not only the internal capability (ATP and production planning) but also the supplier capability about how long the maximum time and how many are to deliver the component.

2.6. *Distribution and Transport Planning*

Distribution planning is very much correlated with transport agreements for shipping consumer goods from manufacturers to customers. Shipments could go directly from the factory or from distribution centers to customers, depending on the order types and distances. This typical distribution channel enhances supply chain integration among manufacturers, distributors and customers, who need planning ahead of time. Furthermore, integrated transport planning decreases the cost substantially. The relatively smaller shipments account for higher costs than larger ones. The distribution and transportation costs also depend on the locations of factories, suppliers, DCs (distribution centers) and TPs (transshipment points). Correlation between distribution and transport planning module and other APS modules as described by Fleischmann (2002) can be summarized in Fig. 11 below:

In this chapter, ASDN is used to investigate the profitability of supply chain networks by considering transportation as well as distribution centers. By applying information from demand and master planning, ASDN enables us to find the supply chain profit, inventory value, and total lead times. Even this software ignores iterative procedures for network optimization. The model is however, can be represented as strategic network planning below.

2.6.1. *Strategic networks planning*

In strategic network planning, firms generally focus on long-term strategic planning and design of their supply chain (see Fig. 6). Therefore, it is related to long-term

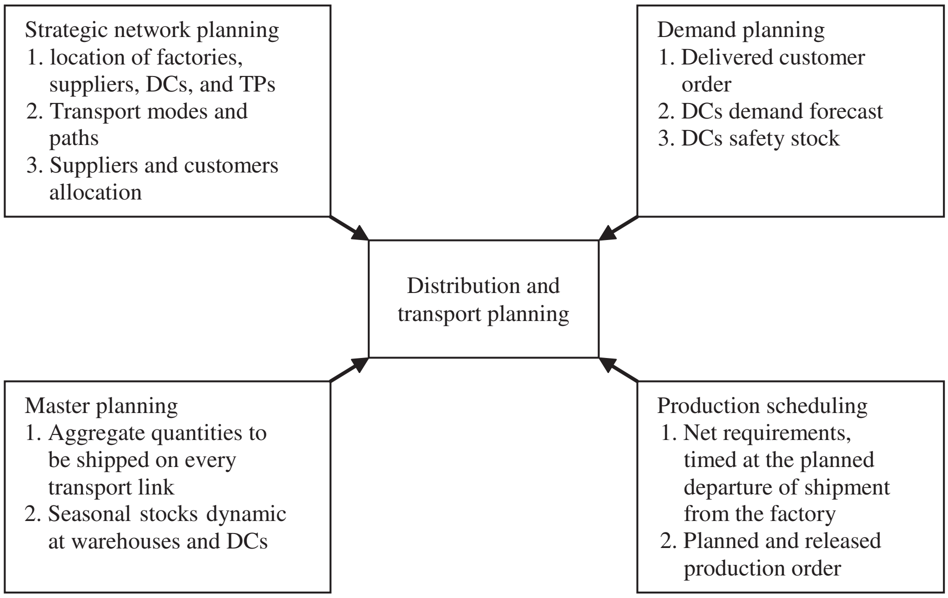

Figure 11. Distribution and transport interfaces.

decisions, such as plant location and physical distribution structure (Meyr *et al.*, 2002). During the process, some compulsory information, for instance the product family structure and market share, potential suppliers and manufacturing capability, is utilized to decide whether this planning is expansion or collaboration. For example, a car company may wish to expand its market into the new area. They may choose to develop their own business by locating some facilities (factories, distribution centers, and warehouses) or consolidating with another existing company. It is also possible to re-evaluate the previous strategic plan, for instance the manufacturer intends to relocate its factories to a country with cheaper labor costs. This brings them advantages such as a cheap labor market, low cost of raw materials, and the opportunities for new business markets locally.

Due to its impact on long-term profitability and competitiveness within a company, the planning depends on aggregate demand forecasting and economic trends in the market. It is, therefore, a challenging task since the planning period ranges from 3 to 10 years, where all the decision parameter conditions may change, for instance customer demand behavior, market power, and supplier capability. This strategy becomes complicated if companies execute their strategic planning infrequently and do not update periodically. The main objective of this type of planning related to value chain re-engineering is to reconfigure the manufacturing process, which is embodied by developing ASDN (Fig. 12). Therefore, the model will collect information from medium- and short-term planning, for instance vendors and distribution facilities among suppliers, distributors, and manufacturers to be optimized against product configuration. The interfaces among them are depicted as follows:

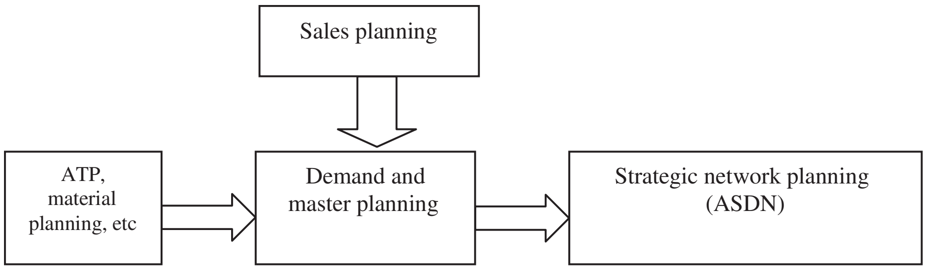

Figure 12. Strategic network planning and customer needs alignment.

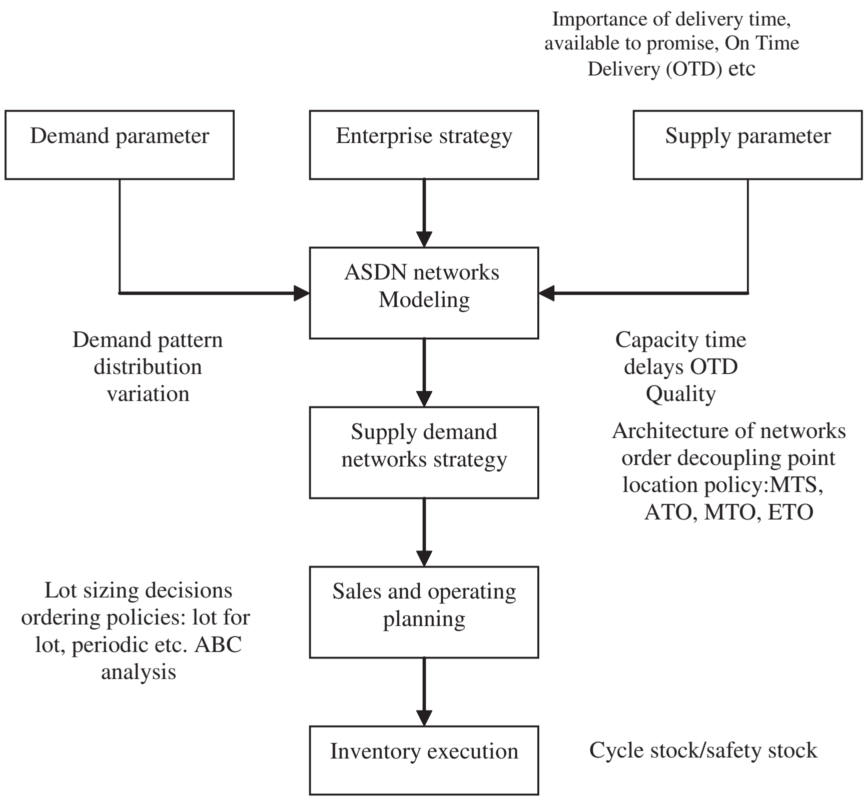

Figure 13. ASDN approach for networks design.

Figure 12 depicts the planning connection to the product database, which is used to reconfigure the demand and master planning where it will be used to reconfigure the strategic network planning. Furthermore, the details of the ASDN operations can be represented as Fig. 13 below.

Beforehand, it is beneficial to study further from the existing APS software in order to find the path for improvement. This report takes two APS software examples, namely SAP APO and ASPROVA APS, and these are described in more detail in the next section.

3. Contribution to APS Software Development

APS has increasingly been used instead of Enterprise Resource Planning (ERP), which is also implemented in several commercials software, for example, SAP APO and ASPROVA. Furthermore, this chapter looks beyond comparison the possible further development of the software by regarding the above architecture as follows.

3.1. *SAP Advanced Planner and Optimizer (APO)*

SAP Advanced Planner and Optimizer (APO) is a well-known software that represents an example of APS software package. SAP APO is designed for supporting the planning and optimization of a supply chain and works both linked to ERP-packages and also on its own. Structures of many other software packages follow the same structure (Buxmann and König, 2000, p. 100):

1. The planning modules consist of procedures for "Demand Planning", "Supply Network Planning", "Production Planning and Detailed Scheduling", and "Available to Promise".
2. User interface (UI) "The Supply Chain Cockpit" gives the chance of visualizing and controlling the structure of logistics chains. The UI facilitates the graphical representation of networks of suppliers, production sites, facilities, distribution centers, customers, transshipment locations. Additionally, by using the Alert Monitor engine it is possible to track supply chain processes and identify event-initiating problems and bottlenecks.
3. Solver is an optimization engine that employs various algorithms and solution procedures for solving supply chain problems. This includes forecast modeling techniques such as exponential smoothing and regression analysis being built in for demand planning, and also branch and bound procedures and genetic algorithms are available for production and distribution planning.
4. Simulation of changes is enabled by an architecture for computing and data-intensive applications that makes it possible for simulations, planning, and optimization activities to be in real time.

In this software, optimization is bounded into optimization range and resources allocation. The optimization range is different according to whether optimization horizon or resources are transferred. The optimization horizon will optimize each activity in the optimization range, however, due to interrelation between activities in these two regions. These fixed activities determine their action according to their flexibility. Below is described the relationship table for scheduling optimization (Table 1).

Another SAP APO facility is networks design. Networks design creates an analysis of entire networks with regards to locations, transportation networks, facility location, and even analysis of current territorial divisions. In practice, these designs

Table 1. Relationship Table in Scheduling Problem by SAP APO.

1st activity	2nd activity	Relationship	Definition
Fixed	Nonfixed	Maximum interval	Latest start or finish date
Fixed	Nonfixed	Minimum interval	Earliest start or finish date
Nonfixed	Fixed	Maximum interval	Earliest start or finish date
Nonfixed	Fixed	Minimum interval	Latest start or finish date

comprise inbound and outbound logistics planning such as sourcing decision, transportation mode determination, and warehouse location evaluation according to different demand supply patterns, varying costs, and capacity constraints.

The discussion on SAP APO produces the following conclusions:

1. The user interface in SAP APO helps the APS planner to investigate the profit performance of the entire supply chain. This report uses ASDN to represent the same objective.
2. Solver optimizer is used in SAP APO to optimize the scheduling problems and demand forecasting. This chapter, however, applies an optimization tool to optimize supply and manufacturing strategy. This chapter enhances the function of optimizer from operational to tactical and strategic levels.
3. SAP APO excludes supply side optimization in terms of long-term planning (Stadtler, 2005), in which it is important to support ATP. This new model, however, puts the planning in the higher hierarchy by positioning material planning collaboration comprises of product development, procurement, and production functions.
4. As well as these advantages, this model has a limitation related to distribution and transport planning, where the optimizer needs to be developed.

3.2. *ASPROVA APS*

ASPROVA APS is developed by the following logic:

Figure 14 is taken from the ASPROVA APS main menu, which exhibits the production scheduling process that is taken by receiving the order and shop floor data to build a production schedule. The scheduling operator receives master data (production capability) in order to issue work instructions and purchase order to the suppliers.

ASPROVA APS, however, is concerned about scheduling operations instead of creating the whole APS components, for instance demand planning, master planning, and transportation and distribution scheduling. Some limitations of this software are:

1. ASPROVA APS does not apply demand planning, for instance capacity or manufacturing strategy planning;

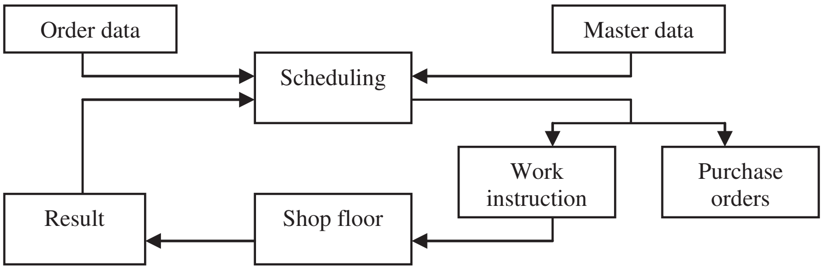

Figure 14. ASPROVA APS operation image.

2. ASPROVA APS does not visualize the supply chain network optimization and
3. The impact of the two limitations is that ASPROVA APS is not able to link itself to supply chain execution program and ERP and is just a stand alone tool.

4. Problem Example

Below is given one problem example of the APS application in one truck industry, which is represented as Fig. 15 below.

The varieties of the above product structure can be composed as (Tables 2 and 3):

From the example, this section will explain step by step the detail of the modeling, as follows:

4.1. *Demand Planning*

The demand planning process is originated from the forecasting part, which is followed by capacity planning, promised lead times, push-pull manufacturing strategy, material and inventory requirements. The planning can be shown in detail by using the following example:

4.1.1. *Forecasting*

Forecasting is required for long-term capacity planning instead of weekly demand. The reason is that this APS is intended to customize orders. This chapter does not go into deep discussion of forecasting techniques because we can use any available technique and it depends on the demand pattern. Otherwise, in general, we can use time series analysis by assuming that demand increases because markets and customers expand continuously.

4.1.2. *Capacity decision*

Capacity decision is established first to give information to the firm with regard to supply and manufacturing strategy. This chapter applies newsboy problem to

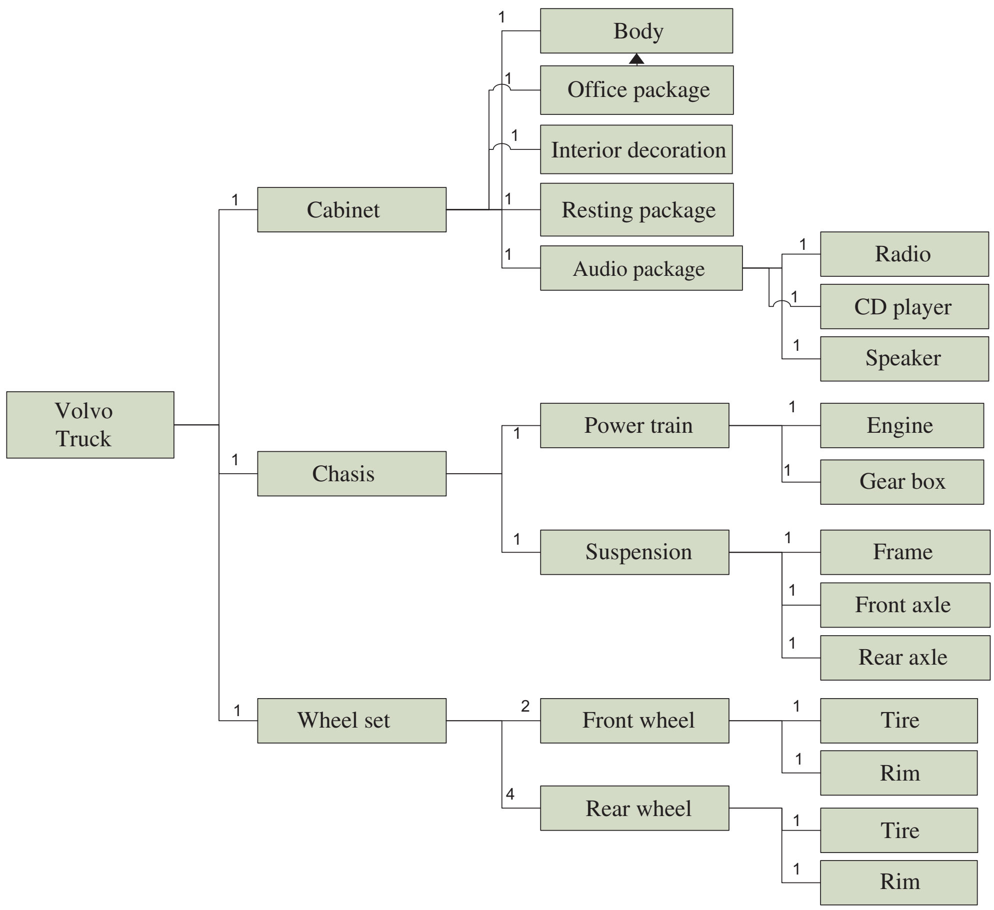

Figure 15. Bill-of-Material (BOM).

minimize over and under stock, as follows:

$$E(C) = h \cdot E(Q - D)^{+} + p \cdot E(D - Q)^{+} \tag{7.1}$$

By operating integration into Eq. (7.1) we get:

$$\begin{aligned} E(C) &= h \cdot \int_{\frac{D}{Q}}^{1} (Q \cdot x - D)^{+} \cdot dx + p \cdot \int_{0}^{\frac{D}{Q}} (D - Q \cdot x)^{+} \cdot dx \\ &= \frac{h \cdot (Q - D)^2 + p \cdot D^2}{2 \cdot Q} \end{aligned} \tag{7.2}$$

By optimizing Eq. (7.2) according to Q, then optimal production quantity (Q) can be determined as:

$$Q_{1,2} = \sqrt{p + h} \cdot D \tag{7.3}$$

Equation (7.3) gives the result of capacity decision.

Table 2. Truck Parts List.

Parts	Model FH1	Model FH2
Body	FHDA	FHDA
Office package	Opl00	Opll0
Interior decoration	FHDA1	FHDA2
Resting package	RP001	RP002
Radio	FH001,FH002	FH003, FH004, FH005
CD Player	6 disc	6 disc
Speaker	Doors	Doors+rearWall
Engine	D13A−360HP	D13A−400HP
Gear box	Powertronic 5sp	Powertronic 5sp
Frame	4″2	6″2
Front axle	FSH 1370	FSH 1370
Rear axle	Hub reduction 1370	Hub reduction 2180
Tire (Front)	385/65-22,5	385/65-22,5
Rim (Front)	FR22,5	FR22,5
Tire (Rear)	315/70-22,5	315/70-22,5
Rim (rear)	FR24,5	FR24,5

Table 3. Required Parameters for Product Manufacturing.

	Model FH1	Model FH2
Penalty cost	1	15
Holding cost	1	4
Annual demand	50	50
Order cost	1	1
Production cost	10	10
Setup cost	4	4
Material cost	1	1
Production rate per month	200	200

4.2. *Master Planning*

4.2.1. *Push-pull manufacturing strategy*

The Customer Order Decoupling Point (CODP) is assigned properly to the components or parts which are fabricated internally. In this chapter, we categorize CODP according to make-to-stock (MTS), assemble-to-order (ATO), or make-to-order (MTO). The objective is to give the least waiting time and operations costs (holding, penalty, and production cost).

We define processing time in one node consisting of supplier delivery time, production and delivery time to the customer, so let us assume that demand has inter-arrival variance (σ_A) and the assembly process has process time variance (σ_B). According to GI/G/1 queue system, we have:

$$L = \frac{\lambda^2 \cdot (\sigma_A^2 + \sigma_B^2)}{2 \cdot (1 - \rho)} + \rho \tag{7.4}$$

where L is the number of order, λ is the demand rate. ρ is the utilization factor. This last equation informs us about whether there is a queue or not in our production line. In order to determine our optimum decision, we use these into our cost function $E(C) = C_P.\mu + C_W.L$, where C_P is order processing cost and C_W waiting cost (Table 4). The above cost function can be generalized into:

$$E(C) = C_P.\mu + C_W.\left(\frac{\lambda^2.\mu.(\sigma_A^2 + \sigma_B^2)}{2.(\mu - \lambda)} + \rho\right) \tag{7.5}$$

Equation (7.5) can be optimized according to μ so that we have:

$$C_P + \frac{(\sigma_A^2 + \sigma_B^2).C_W}{2.(\mu - \lambda)} - \frac{(\sigma_A^2 + \sigma_B^2).C_W.\mu}{2.(\mu - \lambda)^2} = 0 \tag{7.6}$$

$$2.\lambda - \frac{\sqrt{2.(\sigma_A^2 + \sigma_B^2).\lambda.C_W.C_P}}{2.C_P} \leq \mu^* \leq 2.\lambda + \frac{\sqrt{2.(\sigma_A^2 + \sigma_B^2).\lambda.C_W.C_P}}{2.C_P} \tag{7.7}$$

Equation (7.7) can be modified by positing λ as a dependent variable and μ as an independent variable so that we have:

$$\frac{\mu^* + \sqrt{\frac{(\sigma_A^2+\sigma_B^2).\lambda.C_W}{2C_P}}}{2} \leq \lambda \tag{7.8}$$

Table 4. Push-pull Manufacturing Decision for Each Component.

Product	σA	σB	1	Cw	Cpr	μ upper	μ lower	μ actual	MTO/MTS/ATO
Radio	10	10	100	1	5	244,721	155,279	20	MTS
CD player	10	10	100	1	5	244,721	155,279	200	ATO
Speaker	10	10	100	1	5	244,721	155,279	100	MTS
Front tire	20	20	200	1	5	526,491	273,509	200	MTS
Front rim	20	20	200	1	5	526,491	273,509	200	MTS
Rear tire	40	40	400	1	5	1157,77	442,229	200	MTS
Rear rim	40	40	400	1	5	1157,77	442,229	200	MTS
Truck FH1	40	40	100	1	5	378,885	21,1146	200	ATO
Truck FH2	40	40	100	1	5	378,885	21,1146	200	ATO
Power train	10	10	100	1	5	200	155,279	200	ATO

Equation (7.8) is a prerequisite to form postponement, if λ exceeds that limit, form postponement should be changed to time postponement and vice versa. This strategy, however, enables the supply chain to determine the right time for switching from assemble to order to make to order and vice versa. This repositioning strategy can also be used for over production rate.

4.2.2. *Supply strategy*

Supply strategy is defined as deciding which parts should be ordered from the suppliers, and which parts should be produced in-house. This discussion will be separated into two models, make or buy decision, and single or dual sourcing strategy, which is detailed as follows.

In the outsourcing case, suppose the supplier and firm have established a long-term contract by choosing the incentive and penalty cost I and p for the suppliers. The firm gives incentive to the suppliers whenever they can meet the firm customer demands D in the predetermined range at $D \pm \varepsilon_t^*$. If production accuracy $(\varepsilon_t - \varepsilon_t^*)$ is to be a common objective between the suppliers, then, for each i, ε_t^* must maximize the supplier's expected profit, net of penalty and holding costs: (ε_t^*) must solve:

$$\begin{aligned}\max_{\varepsilon_t \geq 0} I.\Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\} - p.\Pr ob\{q(\varepsilon_t) < q(\varepsilon_t^*)\} - h.\Pr ob\{q(\varepsilon_t) \\ > q(\varepsilon_t^*)\} = (p-h)\Pr ob\{q(\varepsilon_t) > q(\varepsilon_t^*)\} \\ -p + (I+p)\Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\}. \qquad (7.9)\end{aligned}$$

The first-order condition for Eq. (7.9) is:

$$(p-h)\frac{\partial \Pr ob\{q(\varepsilon_t) > q(\varepsilon_t^*)\}}{\partial \varepsilon_t} = (I+p)\Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\} \qquad (7.10)$$

That is, the firm and the suppliers choose incentive I, penalty p, and holding h costs, such that the over or under estimation of variance, $\Pr ob(\varepsilon_t - \varepsilon_t^*) > 0$, is minimized, which is the probability of over estimation. From Bayes rule,

$$\Pr ob\{q(\varepsilon_t) > q(\varepsilon_t^*)\} = \Pr ob\{\varepsilon_t > q_t^* + \varepsilon_t^* - q_t\}$$

$$\Pr ob\{q(\varepsilon_t) > q(\varepsilon_t^*)\} = \int_{\varepsilon_t} \Pr ob\{\varepsilon_t > q_t^* + \varepsilon_t - q_t|\varepsilon_t\} f(\varepsilon_t^*) d\varepsilon_t^*$$

$$\Pr ob\{q(\varepsilon_t) > q(\varepsilon_t^*)\} = \int_{\varepsilon_t} 1 - F(q_t^* + \varepsilon_t - q_t) f(\varepsilon_t^*) d\varepsilon_t^* \qquad (7.11)$$

So the first-order condition for Eq. (7.11) becomes:

$$(p-h)\int_{\varepsilon_t} f(q_t^* + \varepsilon_t - q_t) f(\varepsilon_t^*) d\varepsilon_t^* = (I+p)\Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\}$$

In a steady state (i.e., $q_t^* = q_t$), we have:

$$(p-h)\int_{\varepsilon_t} f(\varepsilon_t)^2 d\varepsilon_t = (I+p)\Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\} \qquad (7.12)$$

If ε is normally distributed with variance σ^2 for example, then

$$\int_{\varepsilon_t} f(\varepsilon_t)^2 d\varepsilon_t = \frac{1}{2\sigma\sqrt{\pi}} \tag{7.13}$$

$$\frac{(p-h)}{2\sigma\sqrt{\pi}(I+p)} = \Pr ob\{q(\varepsilon_t) = q(\varepsilon_t^*)\} \tag{7.14}$$

if σ is assumed to be continuously distributed ($N \rightarrow \infty$), then $\sigma = \sqrt{\int (\varepsilon_t - \varepsilon_t^*)^2 p(\varepsilon_t) d\varepsilon_t}$, and Eq. (7.13) becomes:

$$(\varepsilon_t - \varepsilon_t^*) = \frac{(p-h)^2}{2\sqrt{\pi}(I+p)^2} \tag{7.15}$$

By defining the total cost to the firm as $c = h(\varepsilon_t - \varepsilon_t^*)^+ + p.(\varepsilon_t^* - \varepsilon_t)^+ + \frac{\lambda}{D}.C_O$ and replacing $(\varepsilon_t - \varepsilon_t^*)^+$ with $\frac{(p-h)^2}{2\sqrt{\pi}(I+p)^2}$ and doing some integration operations, then we have:

$$c_{outsource} = \frac{h\left(\frac{(p-h)^2}{2\sqrt{\pi}(I+p)^2}\right)^2 + p(\varepsilon_t^*)^2}{2\left(\frac{(p-h)^2}{2\sqrt{\pi}(I+p)^2} + \varepsilon_t^*\right)} + \frac{\lambda}{D} \cdot C_O \tag{7.16}$$

While with in-sourcing we have the following costs function:

$$\begin{aligned} E(TC)_{Insource} &= h \cdot E(Q-D)^+ + p \cdot E(D-Q)^+ + C_D \cdot Z \\ &+ \left[\frac{\lambda}{D} \cdot \left(C_O + \left(C_P \cdot \left(t_S + \frac{D}{\mu}\right)\right)\right)\right] + C_{Pur} \cdot q \end{aligned} \tag{7.17}$$

D is order quantity and Q production capacity. For analysis simplification, we will represent our part inventory as $(Q-D)^+$ and part backorder as or $(D-Q)^+$. Equation (7.17) can be solved by integrating the first two statements as:

$$\begin{aligned} E(TC)_{Insource} &= h. \int_{\frac{D}{Q}}^{1} (Q \cdot x - D)^+ \cdot dx + p \cdot \int_0^{\frac{D}{Q}} (D - Q \cdot x)^+ \cdot dx \\ &+ \left[\frac{\lambda}{D} \cdot \left(C_O + \left(C_P \cdot \left(t_S + \frac{D}{\mu}\right)\right)\right)\right] + C_{pur} q \end{aligned}$$

And we get,

$$\begin{aligned} E(TC)_{Insource} &= \frac{h \cdot (Q-D)^2 + p.D^2}{2 \cdot Q} \\ &+ \left[\frac{\lambda}{D} \cdot \left(C_O + \left(C_P \cdot \left(t_S + \frac{D}{\mu}\right)\right)\right)\right] + C_{Pur} \cdot q \end{aligned} \tag{7.18}$$

where λ is demand rates, C_O order cost, C_P production cost, t_S setup cost, μ production rate, C_{Pur} material cost, and q material quantity.

Our decision is as follows: if $E(TC)_{Insource} > c_{outsource}$, then outsourcing is chosen, otherwise, insourcing is the option.

In addition to sourcing strategy, a procedure is suggested below to choose whether single or dual sourcing is an appropriate option, as follows.

4.2.3. *Single or Dual Sourcing Strategy (Buy Decision)*

In this section, suppose outsourcing is the best option and now the manager is facing a dilemma between single and dual sourcing. In this section, we consider a Bertrand duopoly model (see Gibbons 1992) with price function for retailers given by:

$$q = b - p_1 + \gamma \cdot p_2 + \varepsilon_t^* \tag{7.19}$$

where p_i and p_j is price of the supplier 1 and 2 and γ is the supplier process commonality. Different to Elmaghraby (2000), the buying decision is approached according to price uncertainty. This chapter takes into account quantity uncertainty in order to represent demand variety. It also accommodates Forker and Stannack's (2000) argument of applying competition between suppliers; indeed, the suppliers' cooperation is also considered by applying product compatibility degree γ. In the Cournot game, suppliers choose their own price to maximize their profit by taking their opponent's price as a given. We thus propose a methodology which is similar to the Cournot game, except that we take into account the quantity at infinite time in order to optimize the postponed product compatibility decision resulting from the presence of long-term price contract.

To illustrate, we suppose two suppliers make an auction and the firm makes an opening bid, and afterwards the suppliers cooperate with one another on the chosen price and product compatibility. Restricting attention to the sub-game perfect of this two-stage game, we shall see that if the firm chooses a bid-price, then the predetermined price is used by the suppliers to optimize the auction price, where it is finally used by the suppliers to optimize their production quantity. The firm does not have any benefits by shifting from their bid price, while the supplier also has no reasons to threaten the retailers. From this point on, the game is started from stage 1, where both retailers decide their capacity.

Stage 1: the firm and suppliers optimize their agreed product price according to maximum profit

$$\max_{p1}(b - p_1 + \gamma \cdot p_2 + \varepsilon_t^*)(p_1 - c_{outsource}) \tag{7.20}$$

The first-order condition is:

$$-2p_1 + \gamma \cdot p_2 + b + c_{outsource} + \varepsilon_t^* = 0 \tag{7.21}$$

Similarly, the FOC from second product variant is:

$$-2p_2 + \gamma \cdot p_1 + b + c_{outsource} + \varepsilon_t^* = 0 \tag{7.22}$$

Solving these two equations simultaneously, one obtains:

$$p_2 = p_1 = p_s = \frac{(c_{outsource} + b + \varepsilon_t^*)}{(2-\gamma)} \tag{7.23}$$

Stage 1 explores the price equilibrium between two suppliers. Equal price in this equation shows that the suppliers are working under flexible capacity in all states or the suppliers producing to order and accumulate commitments for all future deliveries. There is always an equilibrium in which all the suppliers set $p_1 = p_2$ in all periods. The suppliers expect profit to be zero whether they cooperate at time-*t* or not. Accordingly, the game time-*t* is essentially a one-shot game in which the unique equilibrium has all suppliers setting $p_1 = p_2$. Furthermore, both buyer and supplier can take advantage of this problem because whenever a supplier increases his selling price, the buyer product price also increases.

In the same way, the firm bargains p_f the supplier's price p_s in order to maximize their profit by taking a maximum margin between product prices to end customer p_b and outsourcing price p_f as follows:

$$\max_{p_f}(b - p_f + \varepsilon_t^*)(p_b - p_f) \tag{7.24}$$

The first-order condition is:

$$2p_f - b - p_b - \varepsilon_t^* = 0 \tag{7.25}$$

Solving that equation for p_f, one obtains:

$$p_b = 2p_f - b - \varepsilon_t^* \tag{7.26}$$

If we assume at the final bargaining period that $p_f = p_s$, then we have:

$$p_b = 2\left(\frac{(c_{outsource} + b + \varepsilon_t^*)}{(2-\gamma)}\right) - b - \varepsilon_t^* \tag{7.27}$$

$$\max_{p_s} \pi_{tot} = \pi_S + \pi_f$$

$$\begin{aligned}\max_{p_s} \pi_{tot} = {} & \max_{p_s}(b - p_f + \varepsilon_t^*)\left(2 \cdot \frac{(c_{outsource} + b + \varepsilon_t^*)}{(2-\gamma)} - b - \varepsilon_t^* - p_f\right) \\ & +(b - (1-\gamma)p_f + \varepsilon_t^*)(p_f - c_{outsource})\end{aligned} \tag{7.28}$$

s.t $(p_f - c_{outsource}) \geq 0$

The first-order condition is:

$$2\gamma \cdot p_f - b - \left(2 \cdot \frac{(c_{outsource} + b + \varepsilon_t^*)}{(2-\gamma)} - b - \varepsilon_t^*\right) - b + (1-\gamma).c_{outsource} = 0 \tag{7.29}$$

Solving that equation for p_f, one obtains:

$$p_f = \frac{\left(2 \cdot \frac{(c_{outsource}+b+\varepsilon_t^*)}{(2-\gamma)} - \varepsilon_t^*\right) + b - (1-\gamma) \cdot c_{outsource}}{2\gamma} \tag{7.30}$$

Equation (7.30) describes the compromise price between the firm and suppliers. This equation is also developed in order to respond to Anton and Yao's (1989) argument about the supplier's collusion.

Stage 2: The firm and suppliers optimize the suppliers' material price

On the suppliers' side, in order to achieve optimal profit, then we have also optimized the material price, as follows:

In the first stage we can find,

$$\max_{p_f}(b - (1-\gamma)p_f) \cdot (p_f - c_m) \tag{7.31}$$

By optimizing Eq. (7.31) against p_f, then the supplier material cost c_m can be found as:

$$b - 2(1-\gamma) \cdot p_f + c_m(1-\gamma) = 0 \tag{7.32}$$

$$c_m = \frac{2(1-\gamma) \cdot p_f - b}{1-\gamma} \tag{7.33}$$

Stage 2 shows that the increasing of product substitutability (γ) will increase the suppliers' total costs. With regard to the result, below a process commonality and pricing-quantity decision is produced by considering long-term relationships between the firm and suppliers (Patterson *et al.*, 1999).

4.2.4. *Component commonality decision between two suppliers*

In the last stage, product design is collaborated between the firm and the suppliers, which is intended to maximize the firm and the supplier's profit. In that case, suppose the suppliers profit function Eq. (7.31) is used to define γ as follows:

$$\gamma = \left(2 - \frac{(c_{outsource} + b + \varepsilon_t^*)}{p_f}\right) \tag{7.34}$$

Stage 1 shows that the increasing of product substitutability (γ) will increase the suppliers' total costs. With regards to the result, below is given a process commonality and quantity decision by considering long-term relationships between the firm and the suppliers (Patterson *et al.*, 1999).

4.2.5. *Selling price strategy*

In this modeling, we define profitability for the buyer as in the Bertrand game, as follows:

$$\max_{p_i}(b - p_i + \gamma.p_j)(p_i - c) \tag{7.35}$$

where p_i and p_j are supplier *i* and *j* the selling price, respectively and *b* is maximum available quantity for the buyer. The first-order condition is:

$$b - 2p_i + \gamma.p_j + c = 0 \tag{7.36}$$

Similarly, the FOC from insourcing is:

$$b - 2p_j + \gamma.p_i + c = 0 \tag{7.37}$$

Solving these two equations simultaneously, one obtains:

$$P = p_i = p_j = \frac{(\gamma + 2).(b + c)}{(4 - \gamma^2)} \tag{7.38}$$

Equation (7.38) shows that higherγproduces a positive impact on product price to the end-customer. From this point on, suppliers' product price p_f is used to find the optimum production quantity for the suppliers as follows.

Stage 2 Quantity decision

This chapter applies a similar principle to that of Singh and Vives (1984), except that we take into account both the price and quantity at infinite time in order to optimize supply chain profitability resulting from the presence of long-term price and production quantity contract. This stage is developed by finding the best price response against price decision, which results from the Bertrand pricing game, and it is shown as follows:

$$p_s(t) = s(p_s - p_s(t));\ p > 0;\ p_s(0) = p_{s(0)}\, p_s = p_f \tag{7.39}$$

In Eq. (7.39), we recognize s as speed of quantity to go to its optimal value. This speed represents how much time is needed by both firms to negotiate their price contract. This notation finally becomes insignificant when such a negotiation is done at an infinite due date, where both firms are assumed to have enough time to analyze their decision. To solve Eq. (7.39), let us set up a current-value Hamiltonian as:

$$H = q(p_s - c) + \lambda s\dot{q} \tag{7.40}$$

S.t Eq.(7.39), $q(t) \geq 0$, where λ is per unit change of objective function (max $\pi_{(q)}$) for a small change in $q(t)$. In the following derivation, we will recognize s and ρ as compound factor and discount rate.

$$\frac{\partial H}{\partial p_s} = p_s - \lambda.s.q(t) = 0 \tag{7.41}$$

$$\dot{\lambda}_1 = \delta.\dot{\lambda}_1 - \frac{\partial H}{\partial q} = \lambda_1(\delta. + .s) - q = 0 \tag{7.42}$$

Steady-state quantity can be found from Eq. (7.42) as:

$$\lim_{s \to \infty} q = \sqrt{p_s} \tag{7.43}$$

We can see that equilibrium quantity is a concave function of price. In conclusion, quantity postponement gives significant impact to the supplier-buyer supply chain whenever both buyers agree to improve their product commonality.

From Eq. (7.43), the total quantities produced by both suppliers can be summarized as:

$$q_1 = q_2 = q^* = 2\sqrt{\frac{(c + b + \varepsilon_t^*)}{(2 - \gamma)}} \tag{7.44}$$

Equation (7.44) gives a solution for the suppliers about optimum capacity, which is used by the suppliers to fulfill orders according to the firm purchase price and quantity. Furthermore, we have ε in Eq. (7.44), which denotes observable demands variance from the firm to the suppliers. This variance gives significant impact to the supplier's willingness to cooperate in product design and at the same time pushes the firm to reduce its demand information inaccuracy to the suppliers (Tables 5 and 6).

4.3. *ATP*

ATP consists of promised lead times and inventory requirement as follows.

Table 5. Sourcing Decision for Each Component.

Product	b	p	h	I	D	C_0	C_{pur}	Error	t_s	μ	C_{prod}	Decision
Body	245	4	2	1	100	1	1000	0,1	2	500	5	Outsourcing
Office package	141	1	1	1	100	1	20	0,1	1	300	5	Insourcing
Interior decoration	141	1	1	1	100	1	15	0,1	1	200	5	Insourcing
Radio	141	1	1	1	100	1	5	0,1	1	20	5	Insourcing
CD player	141	1	1	1	100	1	500	0,1	1	200	5	outsourcing
Speaker	141	1	1	1	100	1	5	0,1	1	100	5	Insourcing
Engine	346	10	2	1	100	1	100	0,1	2	20	5	Insourcing
Gear box	346	10	2	1	100	1	70	0,1	2	20	5	Dual-sourcing
Frame	346	4	2	1	100	1	70	0,1	2	200	5	Dual-sourcing
Front axle	346	4	2	1	100	1	20	0,1	1	50	5	Dual-sourcing
Rear axle	346	4	2	1	100	1	20	0,1	1	50	5	Dual-sourcing
Front tire	346	1	1	1	200	1	5	0,1	1	200	5	Insourcing
Front rim	346	1	1	1	200	1	3	0,1	1	200	5	Insourcing
Rear tire	566	1	1	1	400	1	5	0,1	1	200	5	Insourcing
Rear rim	566	1	1	1	400	1	3	0,1	1	200	5	Insourcrng
Power train	71	1	1	1	100	1	3	0,1	1	200	5	Insourcing
Suspension	218	1	1	1	100	1	3	0,1	1	200	5	Insourcing
Rear wheel	141	1	1	1	200	1	3	0,1	1	200	5	Insourcing
Front wheel	141	1	1	1	200	1	3	0,1	1	200	5	Insourcing
Audio	283	1	1	1	100	1	3	0,1	1	200	5	Dual-sourcing
Cabinet	283	1	1	1	100	1	3	0,1	1	200	5	Dual-sourcing
Chassis	141	1	1	1	100	1	3	0,1	1	200	5	Insourcing

Table 6. Price and Product Platform Decision for Each Component.

Product	γ	pf	c	a	Pb	Total profit
Body	1	261	32	150	372	7717
Office package	1	179	75	150	208	12,692
Interior decoration	1	170	15	150	189	21,109
Radio	1	171	6	150	191	23,104
CD player	1	140	−2	150	131	3159
Speaker	1	171	5	150	191	23,132
Engine	1	411	129	150	672	53,241
Gear box	1	410	73	150	671	63,193
Frame	1	410	72	150	671	63,408
Front axle	1	416	22	150	683	73,574
Rear axle	1	416	22	150	683	73,574
Front tire	1	418	5	150	686	1,27,903
Front rim	1	418	3	150	687	1,28,689
Rear tire	1	683	5	150	1216	3,82,296
Rear rim	1	683	3	150	1216	3,83,876
Power train	1	86	4	150	21	4891
Suspension	1	263	4	150	376	43,579
Rear wheel	1	171	4	150	192	21,021
Front wheel	1	171	4	150	192	21,021
Audio	1	342	4	150	533	60,553
Cabinet	1	342	4	150	533	60,553
Chassis	1	171	3	150	192	23,534

4.3.1. *Promised lead times*

Promised lead times are divided into two different models, namely Make-To-Stock (MTS) Make-To-Order (MTO) lead times, which are used by production scheduling to setup the sequence and it is gathered by applying newsboy vendor problem, as follows:

$$E(C_{LT}) = p \cdot E(LT - LT^*)^+ + h \cdot E(LT^* - LT)^+ \quad LT = \frac{LT^*}{\sqrt{p+h}} \tag{7.45}$$

where: $LT^*_{MTO/ATO} = \frac{Q}{\mu}$ and $LT^*_{MTS} = \frac{d}{s}$, $d =$ distance from factory to customers and $s =$ vehicle speeds. The data required for the promised lead times for truck FH1 and its components are summarized in Table 7.

4.4. *Collaborative Material Planning*

In contrast to the traditional approach of operation management tools, where material requirement follows a top-down hierarchical approach, and starts with Master

Table 7. Promised Lead Times.

Product/parts	Q	μ	p	h	LT	$LT_{1,2}$
Body	100	500	4	2	14	5715
Office package	100	300	1	1	14	9899
Interior decoration	100	200	1	1	14	9899
Radio	100	20	1	1	14	9899
CD player	100	200	1	1	14	9899
Speaker	100	100	1	1	14	9899
Engine	100	20	10	2	14	4041
Gear box	100	20	10	2	14	4041
Frame	100	200	10	2	14	4041
Front axle	100	50	10	2	14	4041
Rear axle	100	50	10	2	14	4041
Front tire	200	200	1	1	14	9899
Front rim	200	200	1	1	14	9899
Rear tire	400	200	1	1	14	9899
Rear rim	400	200	1	1	14	9899
Truck FH1	50	200	1	1	14	9899
Truck FH2	50	200	15	4	14	3212
Power train	100	200	15	4	14	3212
Suspension	100	200	15	4	14	3212
Rear wheel	200	200	15	4	14	3212
Front wheel	200	200	15	4	14	3212
Audio	100	200	15	4	14	3212
Cabinet	100	200	15	4	14	3212
Chassis	100	200	15	4	14	3212

Production Schedule (MPS), the schedule is then detailed into Material Requirement Planning (MRP) by ignoring capacity constraint and assuming fixed lead times. This chapter, however, replaces the MPS and MRP functions by applying collaborative material planning (see Fig. 6) consisting of supplier and buyer integration by including a system dynamics approach. A feedback control mechanism is used to maintain optimal condition, which is represented as a two tanks interaction, as follows:

Figure 16 depicts an interaction between buyer and supplier. This model modifies Holweg *et al.* (2005) model (synchronized supply) by replacing the inventory level with product substitutability degree (γ), by considering product commonality. It is interesting that the model incorporates component residence time in the supplier's (A_1) and manufacturer's (A_R) warehouses, which is useful to give information to the warehouse manager about how long the maximum time is to keep inventory.

Tank R (buyer) production rate depends on Tank 2 (supplier) production rate (and vice versa) as a result of the interconnection of both production rates with

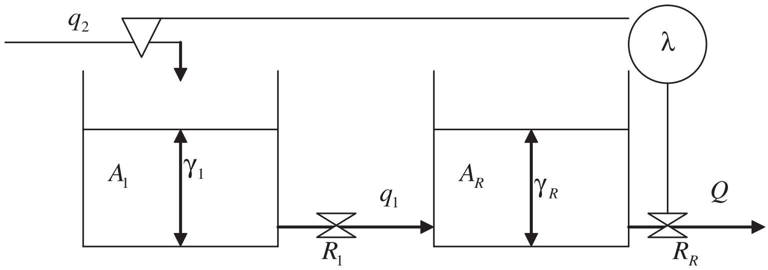

Figure 16. Feedback control application and built to order supply chains.

production quantity q_1. This analogy is taken from fluid dynamics, which states that longer fluid transfer time is caused by high transportation hindrance (R) and production rate difference ($\mu_1 - \mu_R$). If we assume that total stock is the tanks' volume and product substitutability γ is their levels, then, either A_R and A_1 can be found from the manufacturer total stock ($TS_R = SS_R + CS_R$) divided by its product commonality (γ) or

$$TS_R = SS_R + CS_R = z \cdot \sigma_R \sqrt{\frac{1}{(Q-D)}} + \frac{Q}{2(Q-D)} \tag{7.46}$$

$$TS_1 = SS_1 + CS_1 = z \cdot \sigma_1 \sqrt{\frac{1}{q-Q}} + \frac{q}{2(q-Q)} \tag{7.47}$$

$$A_R = \frac{z \cdot \sigma_R \sqrt{\frac{1}{(Q-D)}} + \frac{Q}{2(Q-D)}}{\gamma_R} \tag{7.48}$$

$$A_1 = \frac{z \cdot \sigma_1 \sqrt{\frac{1}{q-Q}} + \frac{q}{2(q-Q)}}{\gamma_1} \tag{7.49}$$

where z is the end customer service level, σ_1 is the supplier delivery standard deviation, and σ_R is the manufacturer delivery standard deviation.

The promised lead times of the manufacturer and the supplier are formulated as:

$$R_R = L_R = \frac{1}{Q-D} \tag{7.50}$$

$$R_1 = L_1 = \frac{1}{q-Q} \tag{7.51}$$

where L_R and L_1 represent the manufacturer and the supplier lead times for in-house production, while in the case where the manufacturer out sources the manufacturing process, then Q and q represent the manufacturer assembly capacity and the supplier production capacity. First, an open loop interacting system is discussed before a further discussion on closed loop built-to-order supply chain.

$$\frac{\mu_R(s)}{\mu_1(s)} = \left[\frac{\frac{R_R}{R_1+R_R}}{\frac{R_1 R_R A_R}{R_1+R_R}s+1}\right] \tag{7.52}$$

$$\frac{Q(s)}{q(s)} = \frac{R_R}{\tau^2 s^2 + 2\varsigma\tau s + 1} \qquad \frac{D(s)}{Q(s)} = \frac{1}{K_R} \tag{7.53}$$

We recognize K_R in Eq. (7.53) which denotes the manufacturer response to customer demands. The higher value signs higher manufacturer responsiveness. Time constant (τ) represents the supplier responsiveness to customer order. ζ in Eq. (7.53) is the decoupling point signal which provides a sign of the customer order penetration point, that is, assembly-to-order (ATO) or MTS. Looking at ζ value helps us to detect lead time variability. Lead times tend to be shorter when $\zeta < 1$ while $\zeta > 1$ yields a sluggish response, while faster response without overshoot is obtained for a critically damped case ($\zeta = 1$). In general, $\zeta < 1$ indicates that the manufacturer is operating under MTS, while $\zeta < 1$ signs ATO. Hereafter, according to the control theory of interacting system, $2\zeta\tau$ and τ^2 can be formulated as:

$$2\zeta\tau = R_R A_R + R_1 A_1 + R_R A_1 \tag{7.54}$$

$$\tau^2 = R_1 R_R A_1 A_R \tag{7.55}$$

Equation (7.55) represents an open loop without information feedback so that supplier has only access to buyer inventory without considering customer demand. Open-loop control can be drawn as Fig. 17.

From this point on, a closed-loop system can be formulated by joining Eqs. (7.50)–(7.55) to be:

$$\frac{q(s)}{q_2(s)} = \frac{R_R}{K_R(\tau^2 s^2 + 2\varsigma\tau s + 1)} \tag{7.56}$$

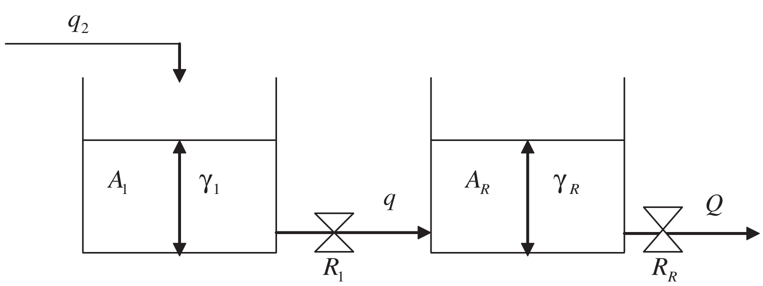

Figure 17. Open loop: Two interacting processes.

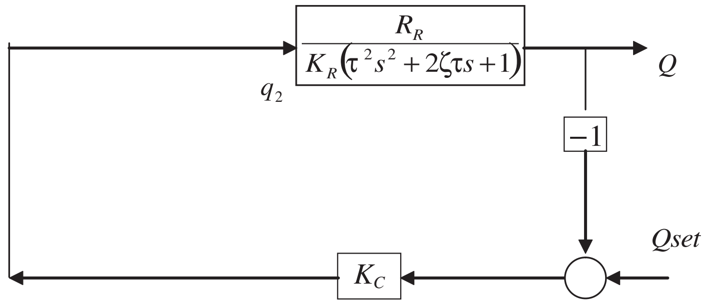

Figure 18. Closed feedback control transfer function.

$$\frac{Q(s)}{q(s)} = K_R = G_R \tag{7.57}$$

With closed-loop feedback control as shown in Fig. 18.

K_C in Fig. 18 represents information visibility between the manufacturer and the supplier. The larger the gain, the more the supplier delivery quantity will change for a given demand information change. For example, if the gain is 1, a demand information change of 10 percent will change supplier delivery quantity by 10 percent. K_C decision is important to the interacting system because it affects simultaneously the supply chain inventory (buyer and supplier) and order lead times. K_C depicts process visibility from manufacturer to supplier so that the higher value signs higher visibility. Information visibility (K_C) needs to be adjusted according to product commonality requirement (see Section 4.2.4) in order to fulfill the lead time requirement. Finally, Fig. 18 can be used to construct a time domain dynamics of synchronized supply by finding its open-loop transfer function as follows:

$$\begin{aligned}\frac{Q(s)}{Q(s)^{set}} &= \frac{K_C \frac{R_R}{K_R(\tau^2 s^2 + 2\varsigma\tau s + 1)}}{1 + K_C \frac{R_R}{K_R(\tau^2 s^2 + 2\varsigma\tau s + 1)}} \\ &= \frac{K_C \cdot R_R}{K_C \cdot R_R + K_R(\tau^2 s^2 + 2\varsigma\tau s + 1)}\end{aligned} \tag{7.58}$$

So that we have roots of denominator as:

$$s_{1,2} = \frac{-\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right) \pm \sqrt{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)^2 - 4\frac{K_R + K_C . R_R}{K_R\tau^2}}}{2}$$

Laplace domain dynamics according to step disturbance is applied in order to represent sudden demand change, which can be inserted directly into Eq. (7.58) and inverted to get the following inversion of the Laplace transform, as follows:

$$\frac{Q(s)}{Q(s)^{set}} = \frac{K_C.R_R/K_R\tau^2}{s\left(s+\frac{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)+\sqrt{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)^2-4\frac{K_R+K_C.R_R}{K_R\tau^2}}}{2}\right)\times\left(s+\frac{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)-\sqrt{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)^2-4\frac{K_R+K_C.R_R}{K_R\tau^2}}}{2}\right)} \tag{7.59}$$

Simplifying Eq. (7.59) then we have:

$$a = \frac{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)+\sqrt{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)^2-4\frac{K_R+K_C.R_R}{K_R\tau^2}}}{2},$$

$$b = \frac{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)-\sqrt{\left(\frac{2\varsigma\tau K_R}{K_R\tau^2}\right)^2-4\frac{K_R+K_C.R_R}{K_R\tau^2}}}{2}$$

Finally,

$$\frac{Q(s)}{Q(s)^{set}} = \frac{1}{s(s+a)(s+b)}, \rightarrow Q(t) = \left(1-\frac{e^{-at}-e^{-bt}}{(b-a)}\right)Q(t)^{set} \tag{7.60}$$

Equation (7.60) presents our process modeling as a closed-loop feedback control. It describes the role of IT in demand management by presenting information exchange between the manufacturer and the supplier.

4.4.1. *Optimum K_C Value*

In this chapter, optimum K_C value can be found by the application numerical method, as follows:

$$LT_{transient} = \frac{Q_{transient}}{D} = \frac{Q^* - \sum_{t=1}^{\infty}\left(1-\frac{e^{-at}-e^{-bt}}{(b-a)}\right)Q(t)}{D} \tag{7.61}$$

where $Q_{transient}$ represents production capacity at ramp-up period. Furthermore, lead times at the normal capacity level can be calculated as:

$$LT_{normal} = \frac{Q^* - \left(Q^* - \sum_{t=1}^{\infty}\left(1-\frac{e^{-at}-e^{-bt}}{(b-a)}\right)Q(t)\right)}{D} \tag{7.62}$$

K_C value can be adjusted so that $LT_{transient} + LT_{normal} = LT^*$. From this result, the suppliers can decide how much they must supply to the manufacturer, according to K_C value.

Below is one example from power train, which is manufactured by ATO strategy. In the previous section example, the data mentioned that power train lead time LT^* is 14 time unit and LT_{normal} is 3,21 time unit. From the data, we find $LT_{transient}$ is 10,79 time unit. For this section, the only new information which is required for the simulation is the supplier capacity, and manufacturer (K_R) and supplier (K_C) responsiveness, which are trial in order to meet the transient lead time requirement. The simulation result is then depicted as follows (Fig. 19).

From the simulation, we have information that K_C, K_R, and γ values are 0,1; 0,1, and 0,4 (independent variables). It is also found that the optimum supplier capacity is 200 units (see Table 11). Furthermore, the results of the other components can be represented as Table 8 that is given.

Inventory requirement can be established from Eq. (7.46) and the results are exhibited in Table 9 below.

We can see from Table 11 that inventory requirement is less than normal requirement whenever we apply s, Q or s, S policy.

4.5. *Production Planning and Scheduling*

In this stage, production planning and scheduling extracts information from demand and master planning such as BOM, order and component lead times and inventory level for each component in order to produce detailed operational scheduling. This approach has been applied in other APS software, for instance SAP APO. The difference is that the application of production reconfiguration onto operational

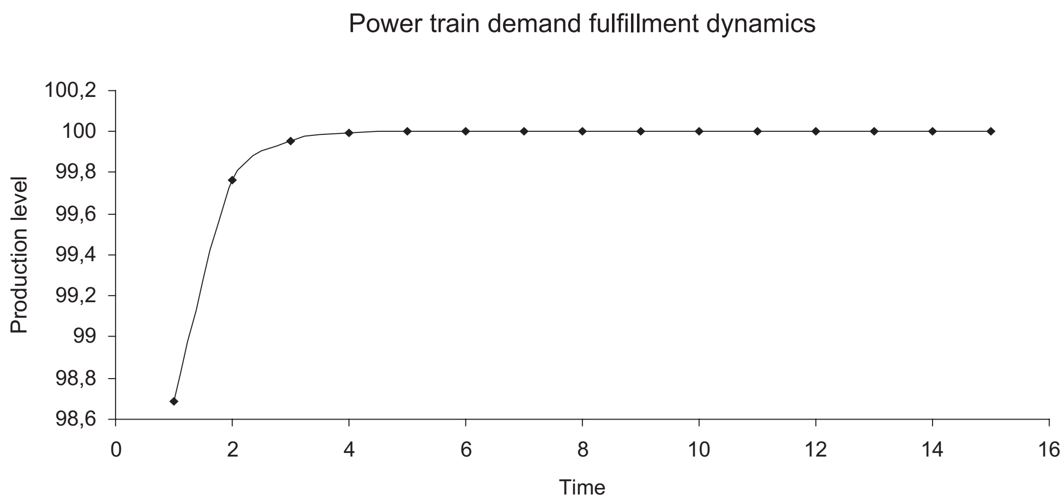

Figure 19. Power train order fulfillment dynamics.

Table 8. Collaboration Between Supplier and Manufacturer.

	D	Q	q	Kc	γ
Body	100	141,4	190	1	0,4
Office package	100	141,4	190	1	0,4
Interior decoration	100	141,4	190	1	0,4
Radio	100	141,4	190	1	0,4
CD player	100	141,4	190	1	0,4
Speaker	100	141,4	190	1	0,4
Engine	100	141,4	160	1	0,4
Gear box	100	141,4	160	1	0,4
Frame	100	141,4	160	1	0,4
Front axle	100	141,4	160	1	0,4
Rear axle	100	141,4	160	1	0,4
Front tire	200	141,4	205	0,2	0,4
Front rim	200	141,4	205	0,2	0,4
Rear tire	400	141,4	405	1	0,4
Rear rim	400	141,4	405	1	0,4
Power train	100	141,4	200	0,1	0,4
Suspension	100	141,4	200	0,1	0,4
Rear wheel	200	141,4	205	1	0,4
Front wheel	200	141,4	205	1	0,4
Audio	100	141,4	200	0,1	0,4
Cabinet	100	141,4	200	0,1	0,4
Chassis	100	141,4	200	0,1	0,4

scheduling is supported by the application of ASDN software by giving the measurement of lead times, inventory value, and profit. The procedure is explored further in Section 4.5.1.

4.5.1. *Production Scheduling*

In order to sequence the tasks of a job shop problem (JSP) on a number of machines related to the technological machine order of jobs, a traveling salesman problem is proposed by considering that it cannot produce illegal sets of operation sequences (infeasible symbolic solutions). The problem can be formulated as in Eq. (7.64) below:

$$\text{Min } t_n \tag{7.64}$$

$$\text{Subject to} \quad t_j - t_i \geq d_i \quad (i, j) \in O \tag{7.65}$$

$$t_j - t_i \geq d_i \quad (i, j) \in M \tag{7.66}$$

Table 9. Safety and Cycle Stock Requirement.

	Z	σ_1	Q	q	$SS1$	$CS1$
Body	1,69	10	141,4	190	2	2
Office package	1,69	10	141,4	190	2	2
Interior decoration	1,69	10	141,4	190	2	2
Radio	1,69	10	141,4	190	2	2
CD player	1,69	10	141,4	190	2	2
Speaker	1,69	10	141,4	190	2	2
Engine	1,69	10	141,4	160	4	4
Gear box	1,69	10	141,4	160	4	4
Frame	1,69	10	141,4	160	4	4
Front axle	1,69	10	141,4	160	4	4
Rear axle	1,69	10	141,4	160	4	4
Front tire	1,69	20	141,4	205	4	2
Front rim	1,69	20	141,4	205	4	2
Rear tire	1,69	40	141,4	405	4	1
Rear rim	1,69	40	141,4	405	4	1
Power train	1,69	10	141,4	200	2	2
Suspension	1,69	10	141,4	200	2	2
Rear wheel	1,69	20	141,4	205	4	2
Front wheel	1,69	20	141,4	205	4	2
Audio	1,69	10	141,4	200	2	2
Cabinet	1,69	10	141,4	200	2	2
Chassis	1,69	10	141,4	200	2	2

where t_n is the total makespan of the three operations within three machines for the three components. t_j and t_i represent the precedent operations j and i where their end and start time cannot be overlapped Eq. (65). Furthermore, the start time operation-(j) cannot overlap the start time operation-(i) in the same machine-M Eq. (7.66). This problem will be solved by applying MS-Excel add-in facility for optimal sequencing problem as follows.

Suppose we intend to schedule an audio assembly where five activities are distributed among radio, speaker, and CD player (The total lead times are 14 time unit. See Table 7). The CD player is produced by following ATO (step 1 to 5) and the radio and speaker by following MTS manufacturing strategy (step 4 to 5) (see Table 4). The detailed manufacturing times and sequence are shown below (Table 10).

The Excel form of representation of this schedule optimization can be depicted as Table 11.

Table 10 shows the MS excel add-in facility snapshot of job-shop scheduling, which is applied to optimize the audio manufacturing schedule. There are five steps in the manufacturing process where J1, J2, and J3 sign steps for the CD player

Table 10. Detailed Audio Manufacturing Machining Time.

	Operations				
Components	1	2	3	4	5
Radio				2	4
CD player	4	5	1	2	1
Speaker				3	2

Table 11. Audio Scheduling Data.

Optimize			Objective		Feasible		
Name	Seq_1	Dir.	Min	State	TRUE		
Search method	Random	Value	13	Value	0		
Problem	TSP	Algorithm	None				
Job	1	2	3	4	5	6	7
Job name	Start	J1	J2	J3	J4	J5	End
Next job	6	3	7	5	2	4	1
Sequence	1	6	4	5	2	3	7
Obj. terms	0	0	0	0	0	0	0
Job data							
	Job names						
Process time	Start	J1	J2	J3	J4	J5	End
CD player	0	4	5	1	2	1	0
Speaker	0	0	0	0	3	2	0
Radio	0	0	0	0	2	4	0
Release time	0	0	0	0	0	0	0

because they must be produced as ATO. J4 and J5 denote assembly processes for the audio package. The speaker and radio do not follow J1–J3 because they are managed as MTS. The results can be summarized in Fig. 20.

Figure 20 exhibits the result of job-shop scheduling by applying Travelling Salesman Problem (TSP). We can see from the figure that the total makespan is reduced from 16 (longest processing time from J1 to J5) to 12 time unit. This results implies that now supply chains, by considering the total order lead times, have a chance to be more flexible because now they have at least 4 time unit allowance (16–12). In value chain perspective, the result allows supply chains to be more competitive by reducing the likelihood of delivery lateness by giving some spaces for uncertain events such as machine down time and changeover.

This scheduling optimization also enables the next planning stage (distribution and transport planning) to optimize the supply chain structure by reducing the order lead times. Finally, by applying the same procedure, we can build detailed scheduling for other components. In any case, assembly and fabrication scheduling is focused on internal factory optimization, which needs to be applied

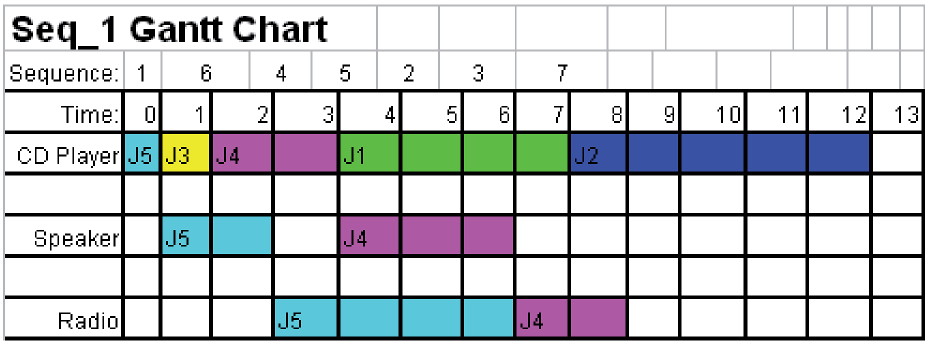

Figure 20. Scheduling Gantt chart.

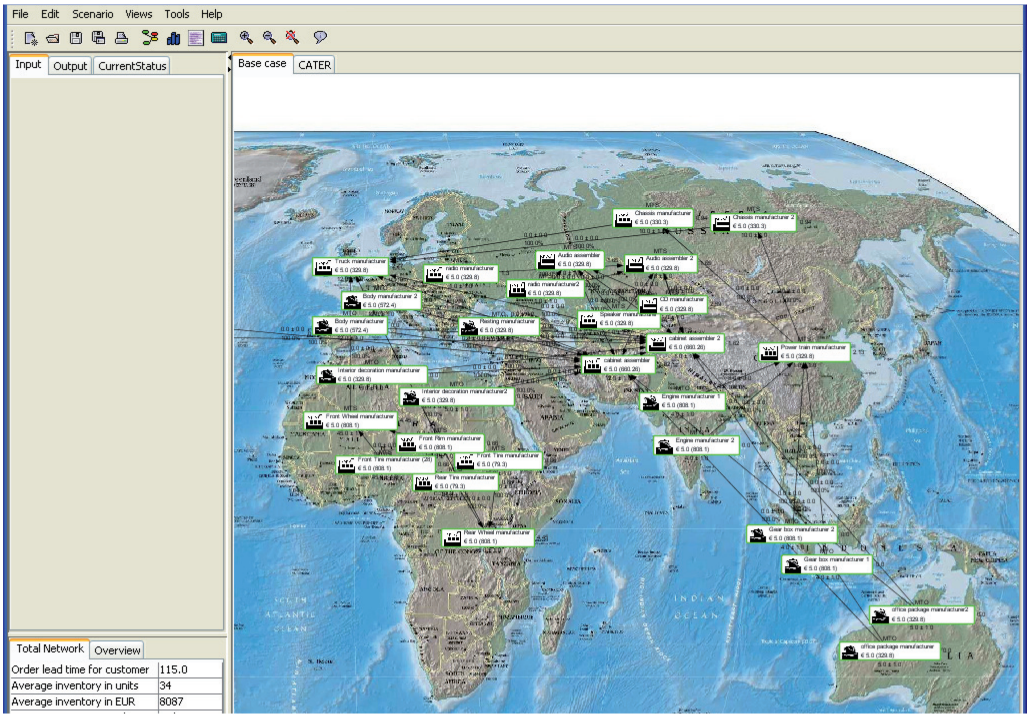

Figure 21. Distributions and transportation planning.

into distribution and transport planning in order to optimize the total lead times as below.

4.6. *Distributions and Transport Planning*

Distribution and transportation planning is used to optimize order delivery activities from supplier to factories and from factories to end users. This section utilizes demand, master, and production planning and scheduling to develop ASDN by optimizing distribution centers and transportation planning, which are exhibited as Figs. 21 and 22.

Financials

	Base case	CATER
Safety Stock Holding Cost [EUR / year]	0.0	0.0
Lead time to customer [days]	48.5	NaN
Cycle time [days]	115.0	0.0
Inventory turns [turns/year]	0.0	NaN
Inventory Holding Cost [EUR]	1446.88	0.0

Close

Figure 22. Financial analysis.

From ASDN simulation, Fig. 21 depicts distribution and transport planning of truck manufacturing, which is situated in the United Kingdom and the manufacturer outsources his or her components or activities across the globe. Furthermore, inventory turn, total lead times, and holding cost (cycle stock and safety stock) are also explored by presenting them in a financial chapter (Fig. 22).

5. Practical Implication

The concept of value chain re-engineering is shown by giving emphasis to information availability among the supply chain and company giving value added in each step of order processing. It ensures that customers have accurate information about the available product configuration and allows them to configure not only the product but also the lead times. This mechanism can be applied within this APS because product structure database and ASDN are linked by using this proposed APS (see Fig. 12). APS in this module gives options for push-pull manufacturing strategy (Section 4.2.1) so that it enables the promise of order lead times as well as optimizing so that it enables the promise of order lead times (Fig. 22) as well as optimizing the aggregate inventory level (Table 8). ASDN in this case measures the value added of APS steps (demand planning, master planning and production planning, and scheduling) through financial analysis (Fig. 22). The implication of ASDN application is that the supply chains can reconfigure the supply chain networks or reschedule the production within the manufacturer's plants until the required performance target is achieved.

Related to value chain re-engineering, this APS model changes the one direction of the value chain to a two-way concept (see Fig. 6) by producing collaboration with both customer and supplier involvement. This collaboration is shown by incorporating suppliers into product platform design (Section 4.2.4) and demand forecasting (Section 4.2.3). APS supports the integration process effectively, whereas ATP module is imbedded into master planning where it also receives information from the product configuration database (customer side), which can be used to select sourcing strategy; thus it also reduces delivery uncertainty because of supplier commitment.

Last but not least, embedding production reconfiguration into distribution and transport planning is a good idea since it has two advantages. The first advantage is that the customer side can reconfigure product structure by considering lead time and this step is possible since ASDN will measure the total lead time at the final simulation. The second advantage is that manufacturers and suppliers can reconfigure their production process by optimizing the manufacturing schedule and reconfigure the push-pull manufacturing strategy. This is the main advantage of value chain re-engineering.

6. Conclusion and Future Research

This chapter has discussed value chain re-engineering, which is represented by a new APS model. We may summarize the results derived from the model as follows.

1. Supply chain collaboration needs to be addressed in the value chain discussion. The value chain cannot be managed solely based on one direction optimization. In fact, both the supply and demand sides must be taken into consideration equally.
2. Technological support and procurement activity need to be involved in the main activities of the value chain. Procurement should have a strategic position in the business activities. Furthermore, in mass customized products, a short product life cycle forces the supply chain to be agile and reconfigurable.
3. The first limitation of this APS is that the model does not incorporate customer and service department interface in assuming that the sales department is replaced by E-marketing. On the other hand, this situation has the advantage of offering a new future research direction with regard to on the possibility of shrinking the organization by diminishing the sales department (see Fig. 6) and changing the firm sales to mass personalization.
4. The second limitation is that there are no any solutions to support the function of sales mode. It would be necessary to conduct future research in personalization of sales function by employing information technology to give added value to the APS.

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